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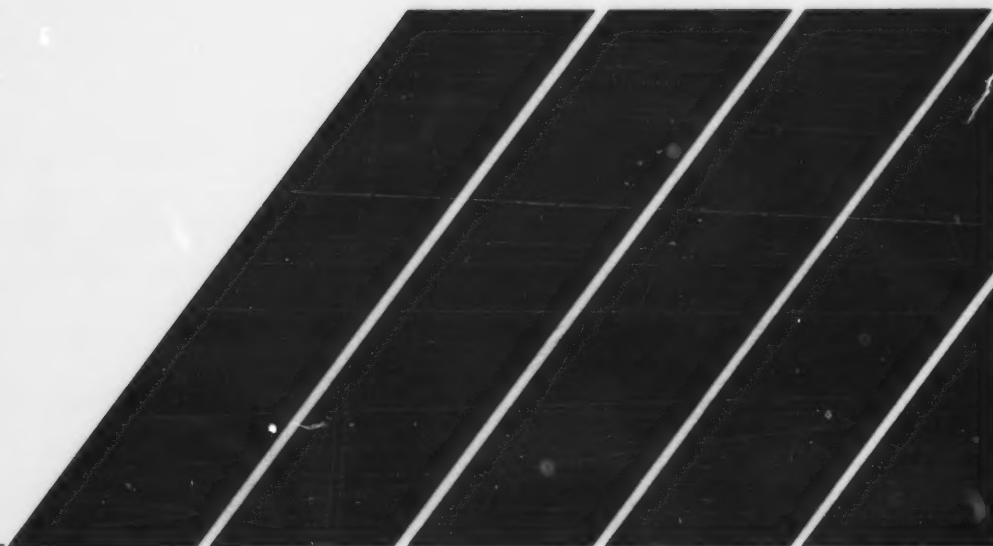
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technologie de
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et des énergies
de remplacement**

**ECONOMICS AND YIELDS OF ENERGY
PLANTATIONS: STATUS AND POTENTIAL**



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**ECONOMICS AND YIELDS OF ENERGY
PLANTATIONS: STATUS AND POTENTIAL**

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TABLE OF CONTENTS

LIST OF TABLES	iii
LIST OF FIGURES	iv
LIST OF APPENDICES	v
EXECUTIVE SUMMARY	vii
1 INTRODUCTION	1
2 SCOPE AND METHODS	4
3 COSTS OF PRODUCTION	5
3.1 Land Costs	5
3.2 Site Preparation	9
3.2.1 Brush Removal	9
3.2.2 Weed Control and Tillage	9
3.3 Planting	12
3.4 Cutting-Back	15
3.5 Plantation Maintenance	16
3.5.1 Fertilization	16
3.5.2 Irrigation	19
3.5.3 Weed Control	20
3.6 Harvesting	20
3.7 Chipping	23
3.8 Drying & Storage	25
3.9 Transportation	26
4 SRIC YIELDS	26
4.1 The relationship between spacing and yield	30
4.2 The effect of rotation length on yields	32
4.3 Reported Yields	34
5 COST OF PRODUCTION ANALYSIS	40
5.1 Methods	40
5.2 Results and Discussion	48
6 SUMMARY AND CONCLUSIONS	56
6.1 Status	56
6.2 Potential	61
6.3 Future Work	62

ii Economics and Yields of Energy Plantations: Status and Potential

7 LITERATURE CITED 63

8 APPENDICES 71

LIST OF TABLES

Table 1	Estimated values for various classes of land in Ontario based on data by Pfeiffer and Cozzarin (1990).	7
Table 2	A summary of cash rental rates (\$/ha/a) for land in various regions of Ontario based on their crop potential (Adapted from Fisher, 1988).	7
Table 3	The cost of various site preparation activities reported in the literature. All costs have been converted to 1990 Canadian Dollars.	11
Table 4	A summary of some of the costs of cutting production reported in the literature.	14
Table 5	A summary of the costs associated with machine planting reported in the literature.	15
Table 6	Harvesting and forwarding costs for two-year-old willow biomass using the Loughry Coppice Harvester. (Personal Communication: B. Hudson, Aberdeen University February, 1991).	22
Table 7	Summary of costs associated with the transportation of biomass from the plantation to the conversion facility.	27
Table 8	Estimated rotations (maximum CAI) for various planting densities based on the regression developed by Woodfin <i>et al.</i> (1988).	33
Table 9	A summary of the ranges for various costs used in the cash flow analysis.	41
Table 10	Amounts and costs of various classes of coal purchased by Ontario Hydro in 1989.	43
Table 11	Summary of the results of the cash flow analysis for biomass production at various planting densities and cost levels. See Appendix G for details.	48
Table 12	A summary of the inputs and outputs for the "current" scenario for energy biomass production. Also shown are the inputs for both unsubsidized and subsidized future scenarios.	50
Table 13	Sensitivity analysis based on 10,000 sph. Values represent the change in Net Present Value per ha (NPV) (in \$/ha or %) resulting from a 10% increase in the cost or revenue item or the MAI, assuming all other factors remain constant.	52

LIST OF FIGURES

- Figure 1 Graphical representation of average yields of all clones. (Kemptville, Maple and Petawawa yields based on a harvest of two-year-old coppice - mid-point through the rotation) 35
- Figure 2. The relationship between heating value and the moisture content of wood. . . . 45
- Figure 3 The relative proportions contributed by the various cost items, to the total discounted cost of production. 54

LIST OF APPENDICES

A	Currency conversion based on IMF inflation data.	71
B	The relationship between planting density and costs using regression analysis on the data of DeBell and Harms (1976)	75
C	A report on a trip to the United Kingdom by W.A. Kenney in February 1991 to discuss the economics of SRIC with the U.K. sub-contractor and to observe a test harvest using the Loughry Coppice Harvester prototype	79
D	A report by Dr. L. Sennerby-Forsse, Swedish subcontractor	89
E	A report by Dr. C.P. Mitchell, U.K. sub-contractor	113
F	Output from cash flow analysis for Canadian energy biomass scenarios	127
G	Comments on the EMR biomass economics spreadsheet: TREE 1-2-3	175

EXECUTIVE SUMMARY

This is the final report for DSS Contract Number 23440-0-9016/01-SZ, funded by the Bioenergy Development Program; Energy, Mines and Resources Canada.

ABSTRACT: *The economics and yields of energy plantations were assessed. Reported costs for most aspects had a wide range. Currently, yields of 10-15 odMg/ha/a are reliably achievable. Using the cost and yield data, and assuming a biomass price of \$40/odMg, a series of cash flow analyses were performed. For the low cost inputs, all scenarios were marginally profitable. For the high cost inputs, none of the scenarios were profitable. A "current" scenario, using figures for contract farming, was not profitable, however this system would break even with a yield of 23.3 odMg/ha/a (a figure within the range of some production clones). A "future" scenario using farm labour with increased productivity, product values, and machinery efficiency yielded a profit-making situation. The addition of incentives increased profitability. There is great potential for the production of woody biomass in Canada as a feedstock for energy and other products. Suggestions for future work were made.*

The environmental concerns associated with the continued use of fossil fuels and nuclear energy, and the continued instability in the Middle East have prompted a re-evaluation of alternative sources of energy. This includes the production of fuel from biomass grown in dedicated, short rotation intensive culture (SRIC) plantations of fast growing trees. SRIC plantations are established on well prepared sites at close spacing, resulting in densities of up to 35,000 plants per hectare and are managed more as an agricultural crop than a forestry enterprise. The production of energy from woody biomass will necessitate encouraging landowners to invest in the production of woody biomass on a large scale. This will only be possible if these landowners can be convinced that such an operation is more economically attractive than the alternatives.

The objectives of this study were: 1) to determine the factors affecting the cost of energy conversion feedstocks produced in SRIC plantations; 2) to determine the factors influencing biomass yield; 3) to identify the inter-relationships between the factors in objectives 1 and 2; 4) to present estimates of potential biomass yields and their associated economics; and 5) to identify

gaps in the knowledge of the economics and yields of biomass production and their inter-relationships.

A review of the international literature revealed a consistent approach to the establishment

Table 1 A summary of the ranges for various costs used in the cash flow analysis.

Operation	Range of Cost (1990 \$Can.)	
	LOW	HIGH
Land Rent (/ha/yr)	50	150
Herbicide (/ha)	65	85
Plough (/ha)	20	80
Disc, 2 passes (/ha)	20	80
Cultivate (/ha)	10	25
Cuttings (/thousand)	25	225
Planting (/thousand)	15	50
Fertilize (/ha/applic.)	100	200
Weed Control (/ha/applic.)	30	40
Cut-Back (/ha)	250	500
Harvest (/ha)	215	1,000
Chip (/odMg)	5	15
Haul (/odMg/km)	0.15	0.25

and management of SRIC energy plantations, but a wide range in the intensity of the various factors and their associated costs exists. Many of these costs were converted to 1990 Canadian dollars; their ranges are presented in Table 1.

Early results from numerous breeding and selection programmes indicate that yields of approximately 10 to 15 odMg/ha/year are already achievable using SRIC techniques. However,

considerably more work is required to identify superior species, families and clones for particular growing conditions. The broad range of yields reported on various sites indicate that mean annual increments of biomass (MAI) in the order of 20 to 25 odMg/ha/yr will be achieved through the proper matching of clones to sites. To achieve and sustain such productivity and beyond will require a concerted research and development effort from the fields of tree improvement, soil science, tree physiology, silviculture, etc.

Cash flow analyses were carried out on a number of scenarios using input costs obtained from the literature and through personal communications with researchers in the field. Because of the importance of planting density on the rotation length and subsequently on the cash flow for a plantation operation, we have considered three planting densities; 5,000, 10,000 and 20,000 stools per ha (sph) using rotations (cutting-cycles) of 6, 5 and 4 years respectively. We have assumed that each plantation will be replaced after approximately 18 years, resulting in 3 to 4 harvests each. Based on the current cost of coal delivered to Ontario Hydro and the equivalent energy density of woody biomass, we used a nominal product value for the delivered biomass of \$40/odMg. This value is considered conservative since it does not account for the added environmental costs associated with the use of coal fired electricity generation, nor does it consider the production of higher valued products and co-products through biochemical or thermochemical conversion processes.

Actual yields will be a function of a number of factors and their interactions. We have initially estimated the cash flow for each plantation scenario using an MAI of 12 odMg/ha/yr. Break-even MAIs for product (delivered biomass) values of \$20, \$40 and \$60/odMg were determined as were break-even product values for 10, 15 and 20 odMg/ha/yr.

The results of the cash flow analyses for the high and low ends of the ranges of the cost inputs for each of the scenarios are summarized in Table 2. For the low input costs, all scenarios produced a positive NPV. The 20,000 sph scenario just broke even. None of the scenarios examined broke-even at the high cost level.

The 10,000 sph scenario was reconsidered using input costs considered representative of the current values in Canada. For this case, we chose a land value of \$75/ha. This amount is in the order of that reported for agricultural land in Ontario currently used for crops such as hay and forage but not for the highest value crops in the most productive regions of the province. It is also consistent with values reported for the prairies. Site preparation costs were based on

Table 2 Summary of the results of the cash flow analysis for biomass production at various planting densities and cost levels, based on a product value of \$40/odMg and 12 odMg/ha/yr and 5% interest rate.

Density (sph)	Rotation (yrs)	Cost Level	PVC (\$/odMg)	NPV (\$/odMg)	IRR	B/C
5,000	4	LOW	31.40	8.60	11.2	1.03
10,000	5	LOW	33.18	6.82	9.7	1.21
20,000	6	LOW	38.11	1.89	6.2	1.05
5,000	4	HIGH	87.86	-47.86		0.46
10,000	5	HIGH	149.22	-103.72		0.39
20,000	6	HIGH	173.37	-132.24		0.30

PVC: present value of the cost

IRR: internal rate of return

NPV: net present value

B/C: benefit cost ratio

the custom farmwork rates reported from three provinces, since these can be assumed to be as close to actual costs as can be expected. These values are as follows: Herbicide and spraying, \$85/ha; ploughing, \$44/ha, discing, \$25/ha; and cultivation, \$21/ha. It should be kept in mind that a subsequent sensitivity analysis revealed that variations in these costs had relatively little effect on the cash flow. Based on the most frequently reported values for the cost of fertilization, we have chosen a value of \$150/ha. A cuttings cost of \$50 per thousand and a planting cost of \$28 per thousand were used. Weed control costs were set at \$30/ha. Again, the sensitivity analysis indicated that this component contributed only a small amount to the overall cash flow. A cutting-back cost of \$375/ha was included. A cost of harvesting of \$800/ha was selected based on the most recent results from the U.K. and Sweden. Similarly, chipping and transportation costs were set at \$10/odMg and \$0.20/odMg/km. These figures are summarized in Table 3.

The total production cost was \$60.76/odMg resulting in a negative NPV (-\$2,133/ha) and a benefit cost ratio of 0.66. The break-even analysis indicated that, at the current product value of \$40/odMg, a MAI of 23.3 odMg/ha/yr (a figure within the range of some production clones) would be required for this scenario and at 10 odMg/ha/yr the product would have to sell for

Table 3 A summary of the inputs and outputs for the "current" scenario for energy biomass production. Also shown are the inputs for both unsubsidized and subsidized future scenarios.

Operation	Range of Cost (1990 \$Can.)		
	Current	Future	Subsidized
MAI (odMg/ha/yr)	12	20	20
Product Value (\$/odMg)	40	45	45
Land Rent (/ha/yr)	75	75	0
Herbicide (/ha)	85	45 ¹	45 ¹
Plough (/ha)	44	27 ¹	27 ¹
Disc, 2 passes (/ha)	25	15 ¹	15 ¹
Cultivate (/ha)	21	13 ¹	13 ¹
Cuttings (/thousand)	50	50	0 (subsidy)
Planting (/thousand)	28	21 ²	21 ²
Fertilize (/ha/applic.)	150	75 ¹	75 ¹
Weed Control (/ha/applic.)	30	20 ¹	20 ¹
Cut-Back (/ha)	375	0 ¹	0 ¹
Harvest (/ha)	800	600 ²	600 ²
Chip (/odMg)	10	8 ²	8 ²
Haul (/odMg/km)	0.20	0.20	0.20
Subsidy (/ha/yr for first 5 yrs)	0	0	300
Production Cost (\$/odMg)	60.76	34.57	22.43
NPV (\$/ha)	-2,133.00	1,777.42	4,529.04
Benefit/Cost ratio	0.66	1.30	2.01

¹ Farm labour instead of contractor

² 25% increase in efficiency

\$69/odMg (close to the current price for hardwood pulp chips in Ontario). This scenario is not economical at this point. However, increasing the MAI to 20 odMg/ha/yr would result in a break-even selling price of \$43/odMg. This is quite encouraging since the productivity of 20 odMg/ha/yr is commonly recognized to be attainable with improved clonal material and silvicultural techniques.

Table 4 Sensitivity analysis based on 10,000 sph. Values represent the change in Net Present Value per ha (NPV) (in \$/ha or %) resulting from a 10% increase in the cost or revenue item or the MAI, assuming all other factors remain constant.

Cost or Revenue Item	Change in NPV	
	\$/ha	%
Product Value	+409	+19.30
MAI	+225	+10.6
Harvest	-143	-6.7
Chipping	-102	-4.8
Land Rent	-89	-4.2
Transport	-82	-3.9
Fertilization	-61	-2.9
Planting	-50	-2.4
Cutting-back	-36	-1.7
Cuttings	-28	-1.3
Weed Control	-13	-0.6
Pre-Plant Herbicide	-8	-0.4
Ploughing	-4	-0.2
Discing	-2	-0.1
Cultivation	-2	-0.1

The relative importance of each cost or revenue item was examined in a sensitivity analysis using the "current scenario" for a plantation of 10,000 sph. The change in the NPV resulting from a 10% increase in each cost or revenue item or the MAI was determined and the results summarized in Table 4. This analysis indicates that the greatest improvement in the NPV for this scenario with result from increasing the biomass yield (MAI), product value and/or reducing the cost of planting and harvesting, chipping and transporting the biomass.

The scenario involving a planting density of 10,000 sph using current input costs and the conservative product value of \$40/odMg will require improving yield from the presently attainable 12 odMg/ha/yr to 20 odMg/ha/yr. It is generally felt that this goal is possible with continued breeding and selection, better matching of clones to sites and the refinement of silvicultural techniques. Because harvesting, chipping and transportation costs contribute such a great deal to the cost of feedstock production, advances in technology in these areas will improve the economic outlook for biomass energy production through short-rotation-intensive-culture.

Having reviewed the current situation, two possible future scenarios were considered:

In the first scenario, the product value increases to \$45/odMg, and the yield improves to 20 odMg/ha/a. Instead of contract labour, the farmer provides his own labour, thus reducing many operational costs. For planting, harvesting and chipping, a 25% decrease in cost is assumed due to an increase in machinery efficiency. Land rent and haulage costs remain the same as in the current scenario. All costs are listed in Table 3.

Using these figures, the production costs become \$34.57/odMg resulting in an NPV of \$1,777.42 and a cost/benefit ratio of 1.30. This scenario is profitable.

In the second future scenario, all figures remain the same as those just noted, with the following exceptions: Idle land is used, therefore land rent is 0. Cuttings are provided free-of-charge for plantation establishment. A subsidy, similar to the set-aside programme in the U.K., is included - \$300/ha for five years. See Table 3.

This scenario is more profitable than the former: Production costs are \$22.43/odMg with an NPV of \$4,529.04. The benefit/cost ratio has risen to 2.01.

The use of farm labour, an increase in productivity, and more efficient machinery will make energy plantations profitable. Subsidies, such as providing planting stock at no charge and establishment incentives, will increase profitability.

There is great potential for the production of woody biomass in Canada as a feedstock for energy and other products:

- Breeding programmes and improved cultural techniques will increase yields.
- Production costs will be reduced by the development of more efficient machinery and cultural techniques.
- The price of woody biomass should increase to its real value. Compared with the combustion of fossil fuels, woody biomass is, at worst, environmentally neutral. If, as currently in Sweden, a "carbon tax" is applied to fossil fuels, woody biomass will become a much more economically attractive fuel. Also, biomass is the potential feedstock for a variety of high-priced products and co-products.
- If the production of environmentally positive and/or neutral fuels is considered important by government, incentives (subsidies) should be provided to encourage energy plantation establishment.
- As the economics of energy plantations improve, trees will become a viable alternative crop for farmers.

While the results of these economic analyses and those reported elsewhere indicate that the unsubsidized production of energy biomass through SRIC is nearing the break-even point, additional research and development is needed. Some important areas for further work are:

- continued, and more intensive, breeding and selection to develop high yielding, stress tolerant clones with uniform growth habit;
- development of cost efficient harvesting systems;

- characterization of promising clones with respect to nutrient-use efficiency, site requirements, and pest/disease resistance;
- continued research into the optimization of planting density, rotation length, and cultural techniques;
- determination of the extent, productivity, location and tenure of land potentially available for SRIC production;
- investigation of the potential for the use of erodible land for SRIC production;
- establishment of demonstration plantations to provide reliable figures on production yields and costs;
- progress in the improvement of economics and yields of energy plantations should be monitored.

RÉSUMÉ

Voici le rapport final concernant le contrat n° 23440-0-9016/01-SZ du MAS, financé par le Programme de développement de la bioénergie du ministère fédéral de l'Énergie, des Mines et des Ressources.

RÉSUMÉ : On a évalué les dimensions économiques et les rendements des plantations énergétiques. Les coûts indiqués pour la plupart des aspects varient considérablement. À l'heure actuelle, des rendements de 10-15 t M. S./ha-an (tonne de matières sèches à l'hectare par an) sont assurément possibles. À partir des données sur les coûts et sur le rendement, une série d'analyses du flux de l'encaisse ont été réalisées sur la base d'un prix de 40 \$/t M. S. pour la biomasse. Dans le cas où les coûts sont faibles, tous les scénarios sont très légèrement rentables. Dans le cas où les coûts sont élevés, aucun scénario n'est rentable. Un scénario "actuel" s'appuyant sur des chiffres basés sur la culture à forfait se révèle non rentable mais, avec un rendement de 23,3 t M. S./ha-an (un résultat possible avec certains clones de production), le système atteint le seuil de rentabilité. Dans un scénario "du futur" basé sur l'utilisation de travailleurs agricoles, une productivité accrue, une valeur supérieure des produits et une plus grande efficacité de la machinerie, on réalise des profits. L'ajout de stimulants augmente la rentabilité. Le Canada offre un grand potentiel de production de biomasse forestière destinée à servir de charge d'alimentation pour la production d'énergie ou d'autres produits. Des suggestions de travaux éventuels ont été présentées.

Devant les préoccupations environnementales que soulèvent l'utilisation continue de combustibles fossiles et le recours à l'énergie nucléaire, sans compter l'instabilité chronique du Moyen-Orient, il est apparu nécessaire de procéder à une réévaluation des énergies de remplacement. On pense notamment à la production de combustible à partir de la biomasse obtenue grâce à des plantations d'arbres à croissance rapide en culture intensive à courte rotation (CICR). Les plantations CICR se font dans des sols bien préparés, selon un espacement réduit et une densité pouvant atteindre les 35 000 plants à l'hectare. La gestion des plantations s'apparente davantage à celle d'une production agricole qu'à celle d'une entreprise forestière. La production d'énergie à partir

de la biomasse forestière exigera que l'on encourage les propriétaires fonciers à investir dans la production de biomasse forestière sur une grande échelle. Pour ce faire, il faudra persuader les propriétaires que l'entreprise présente des avantages économiques supérieurs.

La présente étude avait pour objectif : 1) de déterminer les facteurs qui influent sur le coût des charges d'alimentation pour conversion énergétique produites dans des plantations CICR; 2) de déterminer les facteurs qui ont une incidence sur le rendement de la biomasse; 3) d'établir les rapports entre les facteurs des objectifs 1 et 2; 4) de présenter des estimations des rendements potentiels de la biomasse et de leur degré de rentabilité; et 5) de définir les lacunes au plan des connaissances sur la rentabilité et le rendement de la production de biomasse et des rapports entre ces deux éléments.

À la lecture de la littérature internationale on constate qu'il existe une approche uniforme à l'établissement et à la gestion des plantations CICR, mais que les divers facteurs et les coûts connexes varient considérablement. Un bon nombre de ces coûts ont été convertis en dollars canadiens de 1990; le tableau 1 indique dans quelle mesure ils varient.

Tableau 1 Résumé des variations des divers coûts utilisés dans l'analyse du flux de l'encaisse.

Opération	Variation du coût (\$ Can. 1990)	
	FAIBLE	ÉLEVÉ
Loyer foncier (ha/an)	50	150
Herbicide (/ha)	65	85
Labour (/ha)	20	80
Disque, 2 passages (/ha)	20	80
Travail du sol (/ha)	10	25
Boutures (/millier)	25	225
Plantation (/millier)	15	50
Fertilisation (/ha/applic.)	100	200
Désherbage (/ha/applic.)	30	40
Recépage (/ha)	250	500
Récolte (/ha)	215	1 000
Copeaux /t M.S.)	5	15
Débardage (t M.S./km)	0,15	0,25

Les résultats préliminaires de nombreux programmes de reproduction et de sélection indiquent que des rendements d'environ 10 à 15 t M.S./ha-an sont déjà réalisables à l'aide de techniques CICR. Il faudra cependant beaucoup de travail supplémentaire pour parvenir à identifier des espèces, des familles et des clones supérieurs appropriés à des conditions de croissance particulières. Le vaste éventail de rendements signalés pour divers sites indique qu'un accroissement moyen annuel de la biomasse de l'ordre de 20 à 25 t M.S./ha-an sera réalisable si l'on parvient à bien apparier clones et sites. Si l'on veut obtenir et maintenir un tel niveau de productivité, voire l'augmenter, il faudra des efforts concertés de recherche et développement dans les domaines de l'amélioration des arbres, de la pédologie, de la physiologie des arbres, de la sylviculture, etc.

Des analyses du flux de l'encaisse ont été faites pour un certain nombre de scénarios à l'aide de coûts tirés de la littérature et basés sur des conversations personnelles avec des chercheurs sur le terrain. En raison de l'importance de la densité de la plantation pour la durée de rotation et par conséquent pour le flux de l'encaisse pendant la durée de l'exploitation, nous avons examiné trois densités soit 5 000, 10 000 et 20 000 tiges à l'hectare avec des rotations (cycles d'abattage) de 6, 5 et 4 ans respectivement. Nous avons supposé que chaque plantation sera remplacée après 18 ans environ, donc qu'elles permettront 3 ou 4 récoltes chacune. En se fondant sur le prix actuel du charbon fourni à Ontario Hydro et sur la densité équivalente d'énergie de la biomasse forestière, nous avons utilisé une valeur nominale pour la biomasse fournie de 40 \$/t M.S. Cette valeur est tout à fait raisonnable car elle ne tient pas compte des coûts environnementaux additionnels liés à la production d'électricité par la combustion de charbon ni de la production de produits et de co-produits de valeur supérieure grâce à des procédés de conversion biochimiques ou thermochimiques.

Les rendements véritables seront fonction d'un certain nombre de facteurs et de leurs interactions. Nous avons d'abord estimé le flux de l'encaisse pour chaque scénario à partir d'un accroissement moyen annuel (AMA) de 12 t M.S./ha-an. Les AMA d'équilibre pour des valeurs du produit (biomasse fournie) de 20 \$, 40 \$ et 60 \$/t M.S. furent établis ainsi que les valeurs de produit d'équilibre pour 10, 15 et 20 t M.S./ha-an.

On trouvera en résumé au tableau 2 les résultats des analyses du flux de l'encaisse correspondant aux coûts minimum et maximum pour chaque scénario. Dans le cas des coûts faibles, tous les scénarios débouchent sur une valeur actuelle nette positive. Le scénario comportant 20 000 tiges à l'hectare n'atteint que le seuil de rentabilité tandis qu'aucun des scénarios étudiés n'atteint le seuil de rentabilité lorsque les coûts sont élevés.

Le scénario des 10 000 tiges à l'hectare a été réexaminé à partir de coûts jugés représentatifs des valeurs actuelles au Canada. Pour cette étude, nous avons choisi une valeur foncière de 75 \$/ha. Ce chiffre correspond à la valeur indiquée pour des terres agricoles de l'Ontario servant actuellement à des cultures comme le foin et le fourrage mais pas pour des cultures de valeur supérieure dans les zones les plus productives de cette province. La valeur choisie est également conforme aux valeurs indiquées pour les prairies. Les coûts de préparation des sites sont basés sur les tarifs de l'agriculture à forfait indiqués par trois provinces; on peut donc penser qu'ils traduisent fidèlement la réalité. Voici ces valeurs : herbicide et pulvérisation, 85 \$/ha; labour, 44 \$/ha, disquage, 25 \$/ha et travail du sol, 21/ha. À noter qu'une analyse de sensibilité subséquente a révélé que des variations de ces coûts avaient très peu d'incidence sur le flux de l'encaisse. À partir des chiffres indiqués le plus fréquemment pour les coûts de fertilisation, nous avons choisi une valeur de 150 \$/ha. Nous avons utilisé des coûts de boutures de 50 \$ par millier et des coûts de plantation de 28 \$ par millier. Les coûts de désherbage ont été fixés à 30 \$/ha. Encore une fois, l'analyse de sensibilité a indiqué que cet élément ne contribue que faiblement à l'encaisse totale. Nous avons inclus un coût de recépage de 375 \$/ha. Le coût de récolte a été fixé à 800 \$/ha sur la foi des données les plus récentes du Royaume-Uni et de la Suède. De même, les coûts correspondant à la mise en copeaux et au transport ont été fixés à 10 \$/t M.S. et à 0,20 \$/t M.S./km. Ces données sont présentées de façon succincte au tableau 3.

Tableau 2 Résumé des résultats de l'analyse du flux de l'encaisse pour la production de biomasse à des densités de plantation et à des niveaux de coûts différents, basés sur une valeur du produit de 40 \$/t M.S. et sur un rendement de 12 t M.S./ha-an et un taux d'intérêt de 5 %.

Densité tiges/ha	Rotation (années)	Niveau de coût	VAC (\$/t M.S.)	VAN (\$/t M.S.)	TRI	RCA
5 000	4	FAIBLE	31.40	8.60	11.2	1.03
10 000	5	FAIBLE	33.18	6.82	9.7	1.21
20 000	6	FAIBLE	38.11	1.89	6.2	1.05
5 000	4	ÉLEVÉ	87.86	-47.86		0.46
10 000	5	ÉLEVÉ	149.22	-103.72		0.39
20 000	6	ÉLEVÉ	173.37	-132.24		0.30

VAC : valeur actuelle du coût TRI : taux de rendement interne

VAN : valeur actuelle nette RCA : ratio coûts-avantages

Le coût total de production était de 60,76 \$/t M.S., d'où une VAN négative (-2,133 \$/ha) et un ratio coûts-avantages de 0,66. L'analyse du seuil de rentabilité montre que, avec une valeur actuelle du produit de 40 \$/t M.S., il faudrait un AMA de 23,3 t M.S./ha-an (un résultat possible avec certains clones de production) pour ce scénario et que, à 10 t M.S./ha-an, le produit devrait se vendre 69 \$/t M.S. (près du prix actuel des copeaux pour pâte de feuillus en Ontario). Ce scénario n'est pas économique à ce point. Cependant, le fait d'augmenter l'AMA à 20 t M.S./ha-an se traduirait par un prix de vente d'équilibre de 43 \$/t M.S. Cela est passablement encourageant puisque l'on admet généralement qu'une productivité de 20 t M.S./ha-an est possible grâce à de meilleurs clones et à des techniques sylvicoles améliorées.

Tableau 3 Résumé des entrants et des extrants pour le scénario "actuel" de production de biomasse énergétique. Figurent également les données pour les scénarios du futur non subventionnés et subventionnés.

Opération	Éventail des coûts (\$ can. 1990)		
	Actuels	Futurs	Subventionnés
AMA (t M.S./ha-an)	12	20	20
Valeur du produit (\$/t M.S.)	40	45	45
Loyer foncier (/ha/an)	75	75	0
Herbicide (/ha)	85	45 ¹	45 ¹
Labour (/ha)	44	27 ¹	27 ¹
Disque, 2 passages (/ha)	25	15 ¹	15 ¹
Travail du sol (/ha)	21	13 ¹	13 ¹
Boutures (/millier)	50	50	0 (subsidy)
Plantation (/millier)	28	21 ²	21 ²
Fertilisation (/ha/applic.)	150	75 ¹	75 ¹
Désherbage (/ha/applic.)	30	20 ¹	20 ¹
Recépage (/ha)	375	0 ¹	0 ¹
Récolte (/ha)	800	600 ²	600 ²
Mise en copeaux (/t M.S.)	10	8 ²	8 ²
Débardage (t M.S.)	0.20	0.20	0.20
Subventions (/ha-an pour les 5 premières années)	0	0	300
Coût de production (\$/t M.S.)	60.76	34.57	22.43
VAN (\$/ha)	-2,133.00	1,777.42	4,529.04
Ratio coûts-avantages	0.66	1.30	2.01

¹ Travailleurs agricoles plutôt qu'entrepreneur

² augmentation de 25 % de l'efficacité

Tableau 4 Analyse de sensibilité basée sur 10 000 tiges à l'hectare. Les valeurs représentent le changement de la valeur actuelle nette par hectare (VAN) (en \$/ha ou %) suite à une augmentation de 10 % du coût ou des revenus ou de l'AMA, en supposant que tous les autres facteurs demeurent constants.

Article du coût de revient ou des revenus	Changement de la VAN	
	\$/ha	%
Valeur du produit	+409	+19.30
AMA	+225	+10.6
Récolte	-143	-6.7
Mise en copeaux	-102	-4.8
Loyer foncier	-89	-4.2
Transport	-82	-3.9
Fertilisation	-61	-2.9
Plantation	-50	-2.4
Recépage	-36	-1.7
Boutures	-28	-1.3
Désherbage	-13	-0.6
Herbicide de préplantation	-8	-0.4
Labour	-4	-0.2
Disquage	-2	-0.1
Travail du sol	-2	-0.1

On a étudié l'importance relative de chaque article de coût ou de revenus par le biais d'une analyse de sensibilité s'appuyant sur le "scénario actuel" pour une plantation de 10 000 tiges à l'hectare. On a déterminé le changement au niveau de la VAN résultant d'une augmentation de 10 % de chacun des articles de coût ou de revenus ou de l'AMA et les résultats sont résumés au tableau 4. L'analyse indique que pour obtenir la plus grande amélioration de la VAN, il faut augmenter le rendement de la biomasse (AMA) et la valeur du produit et/ou réduire le coût de plantation et de récolte, de mise en copeaux et transport de la biomasse.

Dans le scénario comprenant une densité de 10 000 tiges à l'hectare, s'appuyant sur des coûts actuels et une valeur du produit modérée de 40 \$/t M.S., il faudrait améliorer le rendement actuellement possible pour qu'il passe de 12 t M.S./ha-an à 20 t M.S./ha-an. On croit généralement que cet objectif est possible si l'on poursuit les efforts dans le domaine de la reproduction et de la sélection, si l'on réussit à mieux apparier clones et sites et si l'on affine les techniques sylvicoles. Comme les coûts de récolte, de mise en copeaux et de transport entrent pour une grande part dans le coût de production des charges d'alimentation, tout progrès technologique dans ces domaines contribuera à améliorer les perspectives économiques de production d'énergie à partir de la biomasse obtenue par culture intensive à courte rotation.

Après avoir examiné la situation actuelle, deux scénarios du futur furent étudiés :

Dans le premier scénario, la valeur du produit augmente à 45 \$/t M.S. et le rendement passe à 20 t M.S./ha-an. Plutôt que de recourir à des travailleurs agricoles, le fermier fournit sa propre main-d'oeuvre, ce qui réduit de nombreux coûts d'exploitation. Pour la plantation, la récolte et la mise en copeaux, on suppose une baisse de 25 % des

coûts grâce à une meilleure efficacité de la machinerie. Les coûts du loyer foncier et du transport sont les mêmes que dans le scénario actuel. Tous les coûts sont indiqués au tableau 3.

À partir de ces données, les coûts de production passent à 34,57 \$/t M.S., ce qui donne une VAN de 1 777,42 \$ et un ratio coûts-avantages de 1,30. Ce scénario est rentable.

Dans le deuxième scénario du futur, tous les chiffres sont les mêmes que ci-dessus sauf ce qui suit : utilisation de terres incultes, donc loyer foncier égal à 0. Les boutures sont fournies gratuitement. On inclut une subvention, semblable à ce qui est accordé en vertu du programme de retrait obligatoire des terres en culture au R.-U., soit -300 \$/ha pour cinq ans. Voir le tableau 3.

Ce dernier scénario est le plus rentable des deux : les coûts de production sont de 22,43 \$/t M.S. avec une VAN de 4 529,04 \$. Le ratio coûts-avantages passe à 2,01.

Le recours aux travailleurs agricoles, une productivité accrue et une machinerie plus efficace feront en sorte que les plantations énergétiques seront rentables. Les subventions, par exemple le fait de fournir gratuitement le stock de plantation, et l'utilisation de stimulants à l'établissement de plantations vont faire augmenter la rentabilité.

Le Canada offre un grand potentiel de production de biomasse forestière pouvant servir de charge d'alimentation pour produire de l'énergie et d'autres produits :

- o des programmes de reproduction et des techniques culturales améliorées feront augmenter les rendements;

- o les coûts de production seront réduits grâce au développement de machinerie et de techniques culturales plus efficaces;
- o le prix de la biomasse forestière devrait augmenter pour atteindre sa vraie valeur. Par rapport à la combustion de combustibles fossiles, la biomasse forestière est, dans le pire des cas, sans effet sur l'environnement. Si, comme cela se fait actuellement en Suède, on impose une taxe sur les hydrocarbures pour les combustibles fossiles, la biomasse forestière deviendra un combustible beaucoup plus intéressant sur le plan économique. En outre, la biomasse peut servir de charge d'alimentation pour une foule de produits et de co-produits de grande valeur;
- o si le gouvernement estime important que l'on produise des combustibles respectueux de l'environnement, il faudrait recourir aux stimulants (subventions) pour encourager la création de plantations énergétiques;
- o à mesure que les plantations énergétiques deviendront rentables, les arbres représenteront de plus en plus une culture de remplacement viable pour les agriculteurs.

Même si les résultats des analyses économiques présentés ici et dans d'autres études indiquent que la production non subventionnée de biomasse énergétique par plantation CICR atteint presque le seuil de rentabilité, il faut que la recherche et le développement se poursuivent. Voici certains domaines importants qui exigent des efforts supplémentaires :

- o poursuivre et intensifier les efforts dans le domaine de la reproduction et de la sélection pour développer des clones à rendement supérieur, résistants au stress et possédant un type de croissance uniforme;
- o mise au point de méthodes de récolte rentables;
- o caractérisation des clones prometteurs en ce qui a trait à l'efficience de l'utilisation des éléments nutritifs, des exigences liées aux sites et de la résistance aux maladies et aux insectes;
- o recherches continues en vue de l'optimisation de la densité des plantations, de la durée des rotations et des techniques culturales;
- o détermination de la superficie, de la productivité, de l'endroit et du type de régime foncier des terres qui pourraient servir pour la production CICR;
- o étude sur la possibilité d'utiliser des terres érodables pour la production CICR;
- o création de plantations de démonstration afin d'obtenir des données fiables sur les rendements et les coûts;
- o il faudrait surveiller les progrès réalisés dans l'amélioration de la rentabilité et des rendements des plantations énergétiques.

1 INTRODUCTION

Humans may have systematically used wood energy for warmth and cooking as early as 500,000 to 200,000 years ago (Lambert *et al.*, 1987). It is only relatively recently that wood has been displaced by fossil fuels as the primary source of energy for non-industrial uses in the developed world (Gilliusson, 1985). While the OPEC oil embargo and Middle East conflicts of the 1970s spawned an interest in the use of alternative sources of energy, interest waned as the price of oil subsequently declined. The environmental concerns associated with the continued use of fossil fuels and nuclear energy and continued instability in the Persian Gulf have prompted a re-evaluation of alternative sources of energy which were previously economically unattractive. Among these alternatives is the production of fuel from biomass grown in dedicated, short rotation intensive culture (SRIC) plantations of fast growing trees.

SRIC plantations are managed using methods more resembling an agricultural system than a forestry enterprise. Such plantations are established on well prepared sites at close spacing, resulting in densities of 10,000 to 35,000 plants per hectare (Zsuffa *et al.*, 1977). Many hardwood species, particularly in the family *Salicaceae* (willows and poplars), have considerable potential in SRIC applications because of their high productivity, their genetic diversity, their ability to coppice and the relative ease with which they can be vegetatively reproduced. Research programmes dealing with the SRIC production of energy biomass are under way in many countries including Canada, The United States of America, Sweden, Finland, The United Kingdom, Ireland, and New Zealand (for a brief description of each programme see Swedish University of Agricultural Science, 1988)

Blom (1986) points out that in the past it was felt that energy plantations would have to compete with food crops for the available agricultural land base. It appears that this is no longer the case in many parts of Europe due to the over production of food. He argues that energy plantations may now actually serve as a partial solution to the problem. In many parts of Europe, the over production of food crops has made it necessary to remove some land from production. The development of biomass energy systems would provide a market for woody

biomass produced on this land as an alternative crop. In the United States, legislation is in effect to remove highly erodible land from production through the Conservation Reserve Program. Again energy biomass could be considered as a crop on such land (Timmons, 1988) provided rotations were long enough to meet the requirements of the C.R.P. legislation.

Pfeiffer and Cozzarin (1990) estimated that a 15 MW plant operating full time (8760 hrs/yr) at a plant efficiency of 0.285 (28.5% efficiency in the steam cycle of a power plant) would require an annual supply of 83,830 odMg of wood, assuming an energy content of 19.8 Gigajoules/oven dried megagram (GJ/odMg). Based on a mean annual increment of biomass (MAI) between 15 and 20 odMg/ha, such a plant would require from 4,000 to 6,000 ha of plantation to supply its feedstock needs for a year. The requirement of such a large land base will necessitate encouraging landowners, be they farmers or utilities, to invest in the production of woody biomass on a large scale. This will only be possible if these landowners can be convinced that such an operation is more economically attractive than the alternatives.

Lyons, (1988) states that, despite the differences in site and climate conditions within the European Community, estimates of biomass production costs from short rotation forestry in various countries have been "fairly uniform, and in the range \$40-\$70/ODT" (1988 \$U.S.) [converted to \$55-\$95 1990 \$Canadian]¹. Typical biomass production costs for a number of Irish scenarios have been estimated (Lyons, 1988). For example, based on a 4 year rotation with 10,000 stools per ha, yield levels of 12.5 odMg/ha and a 2% real discount rate, the delivered feedstock cost was in the range of \$56-68/odMg [\$75-\$92] of delivered fuel. At this level, Lyons was of the opinion that Short Rotation Intensive Culture (SRIC) energy could compete favourably with commercial fuels used by the domestic sector in Ireland. Mitchell (1988) considered a delivered fuel price of \$58/odMg (US, 1983) [\$94/odMg] as indicative of the middle of the range for the U.K. situation. Strauss and Grado (1991) put the delivered cost of SRIC woody feedstocks in the U.S.A. at \$US 39/odMg [\$45/odMg].

¹ See page 4 for method of conversion.

Pfeiffer and Cozzarin (1990) estimated the cost of producing wood chips from conventional forestry operations in Eastern Ontario. By harvesting thinnings with a hauling distances of 10 km and yields of 50 odMg/ha, they estimated a delivered cost of \$44.16/odMg (1990 Can\$). Assuming a 5% long term profit margin this value would rise to \$46.37/odMg. These same authors estimated a delivered cost (including a 5% profit margin) of \$49.73/odMg for clear cutting and stand conversion, assuming yields of 100 odMg/ha.

Many other economic analyses of SRIC have been carried out in Canada, the U.S.A., and Europe. Any such analysis will be specific to the region and time in which it is carried out. As Rose (1976) points out, "Costs exhibit large variation for different locations and are influenced by the scale of an operation, production alternatives and machines chosen. Cost figures become outdated quickly from strong inflationary trends and changing technology." Consequently, conclusions drawn for one system, at one location, in one point in time may not be indicative of the economic viability of a similar system in another place and time. With this in mind, the purpose of this study was to consolidate the results from as many of these reports as possible and to assess their applicability to the production of energy biomass in Canada in the 1990s and beyond. Obviously, the diversity of the Canadian scene is such that it would be impossible to provide conclusive findings for the country as a whole. The economic situation will vary from province to province and even county to county or farm to farm.

This study was undertaken by the Forest Genetics Laboratory at the Faculty of Forestry, University of Toronto and was funded by Energy, Mines and Resources, Canada. The objectives were: 1) to determine the factors affecting the cost of energy conversion feedstocks produced in SRIC plantations; 2) to determine the factors influencing biomass yield; 3) to identify the inter-relationships between the factors in objectives 1 and 2; 4) to present estimates of potential biomass yields and their associated economics; and 5) to identify gaps in the knowledge of the economics and yields of biomass production and their inter-relationships.

2 SCOPE AND METHODS

It was beyond the scope of this study to initiate actual field studies to collect data for the various aspects of biomass production. Consequently, information was obtained from the literature dealing with SRIC and from agricultural statistics from various regions of the country and internationally. As might be expected, these data ranged considerably in time and location. To be able to compare these various data, conversion factors were developed based in currency conversion factors (IMF, 1988) and Canadian inflation rates (IMF, 1990) as reported by the International Monetary Fund. Costs were first converted to Canadian dollars based on the rate of exchange for the year in which the figure was reported. This value was then inflated by the accumulated Canadian inflation rate for the years spanning the date the figures were reported to 1990. These conversion factors are presented in Appendix A. Within the text of this report, we have converted some costs to 1990 Canadian dollar using this method. *These values are presented in square brackets ([]).*

Comparisons based on these factors should be made with caution since they do not account for deviations from the average inflation rate experienced by labour and equipment for a particular operation. Nor do they account for changes in technology which may have altered costs independently of the inflation rate. However, these figures do provide a reasonable means by which the diverse data can be compared.

Unless other-wise noted, yields quoted in Megagrams (Mg) or Tonnes will be on an oven dry (od) basis (i.e., moisture content of 0%) and costs and revenue values will be in 1990 Canadian dollars.

Each major factor associated with the production of energy feedstocks was assessed in terms the costs reported in the literature. When large ranges were noted, an attempt was made to identify why this occurred. Unfortunately, this was often hampered by lack of information with respect to the method used to arrive at the figures in question.

Since biomass yields are seen to be extremely important in determining the cost of production, the relationship between the cost factors and yields were considered and discussed in the following sections.

3 COSTS OF PRODUCTION

3.1 Land Costs

The cost of land plays an important role in determining the cost of biomass production. Stauss *et al.* (1988) determined that plantation maintenance (insect and disease control, property rent, taxes and management) contributed the greatest proportion (37%) to the total cost of biomass production. Of this, land costs were the highest at 52% of the maintenance charges. The primary source of expense in a study by Strauss and Wright (1990) which did not include harvest, storage, drying or transport, was the land rent and property taxes amounting to 42% of the approximately \$17/odMg cost.

Land costs will not affect biomass yields directly as will other factors such as fertilization, weed control or planting density. However, this does not mean that yield and land costs are not related. Strauss and Wright (1990) point out that lower priced land may reduce the cost impact of this very important component, but, if of poorer quality, it would also likely reduce the yield, possibly negating any improvement in the economic outlook. Similarly, Berguson (1987) discusses SRIC on land taken out of agricultural production because of erodibility. He points out that much of the land susceptible to wind erosion is coarse-textured and, because of their low water holding capacity, may not be suitable for SRIC.

Lower cost land may also make it necessary to incur greater expenditures for land clearing, weed control and fertilization. Factors of topography, or obstacles such as stones or particularly wet areas, while reducing the cost of land, may increase production costs by reducing the efficiency of equipment working the land. Land may also have a low cost due to

poor access or long distances to industrialized areas where conversion facilities may be located. In such cases the economic values of the low land costs may be lost due to higher transportation costs.

The cost of land can be incorporated in the total cost of production on the basis of land rent, as an opportunity cost based on the value of an alternative crop such as corn (Strauss and Grado, 1991) or as the cost of interest on the investment in the purchase of land (Bowersox and Ward, 1976; Frappier *et al.*, 1990; Hope *et al.*, 1989). Bowersox and Ward (1976) applied a rate of 6% to the average purchase price of land, while Frappier *et al.* (1990) applied a rate of 13%. Hope *et al.* (1989) used 6.8% which consisted of the average prime rate at the time (10.8%) less the rate of inflation (4%). Gardner *et al.* (1983) considered land rental to range between 5% and 10% of the purchase price and set the rate at 7% for their analysis. Based on an average land cost of \$750/ha, the cost of land rent in their study was \$52.50/ha [\$86].

Pfeiffer and Cozzarin (1990) interviewed agricultural representatives, foresters, field economists and real estate brokers in Eastern Ontario and arrived at the figures for land costs (presumably 1988 Can\$) presented in Table 1. Based on these data, lease rates are between 15% and 40%, a range much higher than that used by Hope *et al.* (1989) and Gardener *et al.* (1983). In their study, Pfeiffer and Cozzarin (1990) used a land value of \$80/ha/yr for poplar production. Strauss and Wright (1990) set the cost of land rent at \$85/ha/yr [\$100/ha/yr].

The rental rate for land may be derived directly from rates applied to land rented for agricultural production. According to the 1985 census (Fisher, 1988), 25% of Ontario's farmland was rented. The average cash rent paid for Ontario Farmland in 1988 was \$99/ha and ranges from \$27/ha in Northern Ontario to \$185/ha in Southwestern Ontario. Growers in Southwestern Ontario produce large volumes of specialty and seed crops which command a higher cash rent per hectare. Cash rents in Eastern Ontario, the region which has thus far received the most attention with respect to SRIC of woody crops, ranged from \$30 to \$44/ha. A break-down of cash rental rates for various crops in each of the regions and for the province

Table 1 Estimated values for various classes of land in Ontario based on data by Pfeiffer and Cozzarin (1990).

Type of land	Purchase Price	Lease
	\$/ha	\$/ha/yr
Class 1 & 2 farm land	400-1000	120-160
Class 3 & 4 (marginal) farm land	100-300	30-70
Drained & level forest land	150-250	50-100
Rolling & stoney forest land	100-200	30-75
Poorly drained forest land	75-150	15-50

as a whole is presented in Table 2. Data for Northern Ontario were insufficient to provide meaningful results. Note the wide range in land rental values for this relatively small (on a national level) geographic region.

Table 2 A summary of cash rental rates (\$/ha/a) for land in various regions of Ontario based on their crop potential (Adapted from Fisher, 1988).

Region	Specialty	Corn	Soybeans	Hay	Forage	Pasture
Southwestern	551.03	163.09	150.73	98.84	69.19	49.42
Southern	316.29	113.67	86.49	N/A	59.30	N/A
Western	222.39	108.72	130.96	64.25	54.36	44.48
Central	256.98	59.30	54.36	39.54	32.12	27.18
Eastern	N/A	79.07	N/A	32.12	32.12	37.07
Average	341.00	118.61	123.55	49.42	44.48	39.54

Domtar has established plantations of hybrid poplar to supply its Cornwall, Ontario mill. This company considers the production of pulp mill feedstocks using SRIC to be profitable and attributes this, at least partially, to the fact that they are able to obtain suitable land at an annual rent of \$25/ha (Pfeiffer and Cozzarin, 1990). Note that this value is at the extreme low end of the array of land rents cited in Table 2.

For Manitoba, Kyle and Therrien (1991) used land investment costs in their crop budget recommendations for various crops, based on 9% of the purchase price of the land. This value was \$70.05/ha for all crops except corn and peas, for which they used a value of \$113.20/ha. They also include the cost of land taxes at a rate of \$12.36/ha and \$16.06/ha for the two classes of crops, respectively.

In Alberta, the average cash rent for crop land for 1989 ranged from \$37/ha to \$74/ha depending on the region (Alberta Agriculture, 1990).

Gardner *et al.* (1983) argued that the cost of land for SRIC in Eastern Ontario could be 0 in some cases. For example, the land may have been purchased for other reasons, and the unused portion, which would have an opportunity cost of 0, could be used for hybrid poplar production. They also suggest that costs for land purchased for SRIC could eventually be recovered when the land is sold. In fact, Hope *et al.* (1989) point out that in times of inflation, the speculative value of land ownership offers benefits above those received from crop production. If land values increased at a rate greater than the general inflation rate, the sale of land after its use for SRIC may result in land purchase ultimately resulting in a revenue.

It could also be argued that a nil land cost could be used for idle land; that is land out of production due to agricultural surpluses, erosion or other environmental problems.

For the purpose of this study, a range of land rental rates between \$50 and \$150 per ha were considered. This is consistent with a range of rental rates for hay and corn in Ontario

(Table 2) and reported rental rates in the Prairie Provinces. It encompasses the values used by Gardner *et al.* (1983, values inflated to 1990 dollars) Strauss and Wright (1990), Pfeiffer and Cozzarin (1990) and Iogen (1990). This range of values does not include the type of land which might be more suited to growing specialty crops such as vegetables, since it is unlikely that energy biomass could compete with such high value products. Nor does it consider the situation where land has little or no opportunity costs such as might apply to idle agricultural land or land taken out of agricultural production for other reasons.

3.2 Site Preparation

3.2.1 Brush Removal

The removal of brush from the site could contribute considerably to the cost of site preparation. Iogen (1990) estimated that \$500/ha would be required for the clearing and stumping of light brush in Eastern Canada and quoted the P.F.R.A. as indicating a cost of \$170 [\$200] to \$300/ha [\$350] in 1986 for Western Canada. Because of the variation in the distribution and types of such brush, it would be very difficult to estimate the cost involved in its removal. Consequently, we have assumed that the land will be under grass and will not have significant quantities of brush.

3.2.2 Weed Control and Tillage

Just as proper weed control has come to play a very important part in the higher yields experienced by modern agriculture, the success of biomass production through SRIC will be dependent on this operation. In conventional hardwood plantation establishment, good weed control is considered an absolute necessity (Burke and Williams, 1973; Von Althen, 1981). Weeds will compete with the crop for light as well as soil moisture and nutrients; they may cause mechanical damage by smothering young coppice growth in the fall; weed growth may

reduce air circulation and hence increase the incidence of disease; and weeds may increase early losses due to animal damage by providing cover for rodents.

Von Althen (1986) demonstrated the impact of complete chemical weed control versus mowing on the height growth on black walnut and sugar maple plantings. The black walnut in the chemically weeded area exhibited a 700% increase in height growth over the mowed area with similar dramatic results for the maple. While these species are not being considered for SRIC, this example does serve to illustrate the dramatic effect that good weed control can have on the growth of hardwoods.

Pre-planting weed control in SRIC plantations will most likely consist of a combination of chemical and mechanical operations. Since the mechanization of subsequent operations (i.e., planting and harvesting) will require that the land be relatively flat and free from debris, site preparation methods will be similar to those employed in the agricultural industry. The somewhat limited array of herbicides currently registered for forestry operations is one area where the chemical weed control in SRIC plantations may differ from conventional agriculture.

The killing of vegetation using a broad spectrum herbicide, usually glyphosate (Roundup), followed by extensive tillage appears to be a standard practice in SRIC plantation establishment. Once the vegetation has been killed, the land is ploughed, disced (twice over) and cultivated. This site preparation is done in the fall prior to planting and the land is "capped" with a pre-emergent herbicide, such as simazine, to reduce the impact of new weed growth in the spring. Some of the costs reported for the various site preparation activities are summarized in Table 3 (all costs converted to 1990 \$Canadian).

The cost of spraying herbicides ranges from \$6 to \$42 per ha. If the high value of \$42 per ha reported by Gardener *et al.* (1983) is deleted, the range in values is reduced considerably to about \$6 to \$16. The high end of this range coincides with the reported custom farmwork rate for Ontario (Burgess and Wind, 1989), and the low end with the custom rates reported for

Table 3 The cost of various site preparation activities reported in the literature. All costs have been converted to 1990 Canadian Dollars.

Source	Cost per ha in 1990 Canadian Dollars			
	Spray	Plough	Disc	Cultiv.
Alberta Agriculture, 1990 ¹	6.17	42.00	18.50	12.00
Blankenhorn <i>et al.</i> , 1985	5.97	30.91	32.53	
Burgess and Wind, 1989 (Ontario) ¹	16.46	43.58	25.11	21.37
DeBell and Harms, 1976	15.98	75.70	39.50	
Gardener <i>et al.</i> , 1983	42.39	76.29	33.91	67.82
Pfeiffer and Cozzarin, 1990	12.36	36.96	24.72	
Saskatchewan Agriculture, 1990 ¹	5.00	34.47	16.63	9.00
Sibal, 1987	6.54	19.90	16.20	11.35
Strauss <i>et al.</i> , 1988			9.21	5.53
Strauss and Wright, 1990	6.55	45.85	15.72	
Strauss and Grado, 1991		51.67		
Techtrol, 1990		43.00	29.00	24.00

¹ Custom farmwork rates

Alberta and Saskatchewan.

The 1990 cost of Roundup is \$12.90/litre (Co-Op Stores, Guelph, Ontario). At the lowest rate for annual weeds (2.2 l/ha) (OMAF, 1988) the cost of materials for this application would be \$28.38/ha. Rates as high as 12 l/ha (\$155/ha) may be required to control perennial weeds and 7 l/ha (\$90/ha) may be required to control quack grass (OMAF, 1988). We will assume a rate of 2.2 l/ha for a range in total cost of \$35 to \$45 per ha for the glyphosate application.

Simazine costs \$9.30/kg (Co-Op Stores, Guelph, Ontario) and OMAF (1988) recommends a rate of 2.5 kg/ha for a cost of \$23.25/ha. This cost, incorporated with the application costs results in a range of total costs, of about \$30 to \$40 per ha. The total cost for the herbicide treatment for site preparation will be in the range of \$65 to \$85 per ha including materials and application.

The range in costs for ploughing was \$20 to \$80/ha with the custom farmwork rates for Ontario, Alberta and Saskatchewan falling near the middle of this range.

The range of discing costs reported in the literature is \$9 to \$40/ha. In most cases, two passes are recommended so that this range could be considered \$18 to \$80 per ha or a range virtually identical to that for ploughing. Again, the custom rate for Ontario is \$25/ha (\$50 for two passes) which is near the mid-point of the reported range. The custom rates for Alberta and Saskatchewan are closer to the lower end of this range.

The final stage of site preparation is cultivation. The range of values is \$6 to \$70, an extreme range indeed. If the highest and lowest values are disregarded, the range becomes \$11 to \$24/ha. The custom farmwork rate for Ontario of \$21.37/ha is consistent with the most frequently reported values of about \$20 to \$24, but the custom rates for Alberta and Saskatchewan are again closer to the lower end of the range. We have chosen to use a range of \$10 to \$25/ha

3.3 Planting

The cost of establishing the plantation after all site preparation has been completed will be the sum of the cost of the planting material (cuttings) and the cost to plant them. Obviously, the cost of establishment on an area basis will be governed by the number of stools (cuttings) per ha to be planted. For this reason, the cost of establishment has been presented here expressed as the cost of materials and planting based on the cost per thousand (/K). These

values will then be expressed on an area basis for different planting densities within the cash flow analyses.

Table 4 presents the estimated costs of cutting material which have been reported in the literature. These values are expressed in the original values and have been converted to 1990 Canadian dollars for comparison purposes. The cost per thousand ranges from \$24 to \$224. The value of \$200 reported by Mr. McDonough of the Ontario Ministry of Natural Resources is based on actual cost estimates for the production of 400,000 poplar cuttings at the Ministry's Kemptville Nursery. The superintendent at that facility indicates that a very large component of that cost is associated with weed control. As fewer herbicides are available, more money must be spent on hand weeding, at an ever increasing labour cost. Note that this high value is consistent with that reported by Woodfin *et al.* (1988) and the average of an actual costs associated with a number of SRIC trials established in the U.K. (Mitchell *et al.*, 1989a).

Woodfin *et al.* (1988) indicate that plantation establishment costs increase logarithmically as planting densities increase. DeBell and Harms (1976) provided cost data for materials and planting for 5 planting densities. We determined the relationship between planting density and costs using regression analysis with these data. The results of this analysis are presented in Appendix B. Based on these results, the data presented by DeBell and Harms (1976) would range from \$20-\$30 (1990 Can\$) for the planting stock given a range in densities of 3,000 to 20,000 stools per ha.

A summary of the estimated costs for machine planting is presented in Table 5. The cost of machine planting reported in the literature ranges from \$12/thousand to \$50/thousand (1990 Can\$). The data for planting costs presented by Woodfin *et al.* (1988) was assessed in a manner similar to that for the cost of cutting material (Appendix B). The range of costs in this case was from \$7 to \$23 (1990 Can\$) and again compared favourably with the figures reported by others,

Table 4 A summary of some of the costs of cutting production reported in the literature.

Source	Cost/Thou.	
	Reported	1990 Can.\$
Blankenhorn <i>et al.</i> , 1985	US\$23.37	42.00
DeBell and Harms, 1976	US\$18.00	48.00
Dutrow and Saucier, 1976	US\$10.00	24.00
Gardner <i>et al.</i> , 1983	Can\$25.00	42.00
Mitchell <i>et al.</i> , 1989 Summary of 6 reports.	£80.00	224.00
T. McDonough OMNR pers.com., 1991 see text for details	Can\$200.00	200.00
Perman, 1985	US\$25.00	42.00
Pfeiffer and Cozzarin, 1990	Can\$34.00	34.00
Sennerby-Forsse, Appendix D	SEK300.00	62.00
Sibal, 1987	US\$20.00	30.00
Strauss and Wright, 1990	US\$50.00	58.00
Woodfin <i>et al.</i> , 1988	US\$120.00	180.00

particularly if the highest value of \$50/thousand reported by Pfeiffer and Cozzarin (1990) is not considered.

For our analysis, we used a range of values for the cost of cuttings of \$25 to \$225 per thousand and a range in costs for planting of \$15 to \$50 per thousand. This translates to a range in the total cost of establishment (stock + planting) of \$40 to \$275 per thousand.

Table 5 A summary of the costs associated with machine planting reported in the literature.

Source	Cost/Thou.	
	Reported	1990 Can.\$
Dutrow and Saucier, 1976	US\$12.70	31.00
Perman, 1985	SEK159.00	29.00
Pfeiffer and Cozzarin, 1990	Can\$50.00	50.00
Sibal, 1987	US\$12.00	18.00
Strauss and Wright, 1990	US\$10.48	12.00
Woodfin <i>et al.</i> , 1988	US\$20.00	27.00

3.4 Cutting-Back

The value of stimulating the production of coppice growth is demonstrated by the fact that coppice yields are often reported to be between 20% and 100% greater than first rotation (un-coppiced) yields (Cannell and Smith, 1980; Mosseler *et al.*, 1988; Perlack *et al.*, 1985). Despite this well recognized aspect of coppice management, few economic analyses have included a cost for cutting-back the first year's growth after planting. It is our opinion that to omit this operation will result in an over-estimate of the yield which could be expected in the first rotation. Little information is available with respect to cost estimates for cutting-back, however, Mitchell *et al.* (Appendix E) include a cost of £200/ha [\$500]. We have included this cost in our analyses as a range of \$250 to \$500/ha to be carried out after the first years growth. This operation will also result in a delay of the first commercial harvest by one year.

3.5 Plantation Maintenance

Once the plantation has been established, certain periodic operations will be required to maintain productivity.

3.5.1 Fertilization

The intensive cultivations of trees with harvesting occurring every 2 to 10 years can be expected to remove a large proportion of the nutrients from the site. Consequently, to optimize yields and to ensure the sustainability of SRIC, the addition of fertilizers to the site will most likely be necessary. For example, Bowersox and Ward (1976) estimated that the addition of calcium, nitrogen and phosphorous to a SRIC hybrid poplar plantation in Pennsylvania could be expected to increase first rotation yields by approximately 60%. Lothner (1986) quotes studies which indicate that fertilization of hybrid poplar plantations can increase growth from between 50% and 400% depending on the site and the amount of nitrogen applied.

Cushman and Ranney (1982) suggest that the greatest fertilizer effects are noticed on better sites since other limiting factors such as poor drainage, may be of greater importance on the poorer sites. Lothner (1986) indicates that other studies have shown the reverse to be true. Often the results of fertilization are not noticed until the second year with effects increasing with age. This could possibly be due to the root systems of fertilized trees being better established in the earlier years (Blankenhorn *et al.*, 1986).

While fertilization generally improves biomass yields to varying degrees, it is not a foregone conclusion that this will always be the case, and a significant clone x fertilizer interaction effect is not uncommon (Berguson, 1987; Simon *et al.*, 1990; personal communication: R.F. Kopp, College of Environmental Sciences and Forestry, State University of New York, Syracuse, N.Y. December, 1990). Berguson (1987) noted that in some cases the application of both N and P actually depressed biomass yields. This negative impact of

fertilization on yield was also noted in a study by DeBell and Radwin (1979, as reported by Fege, 1981) which examined the effect of pulp mill effluent on cottonwood and red alder. While yields for cottonwoods increased with fertilization, the alder actually exhibited a yield depression following fertilization. Kopp also indicated an apparent yield depression in three of six willow clones tested following the fertilization of test plots in New York State (personal communication: R.F. Kopp, College of Environmental Sciences and Forestry, State University of New York, Syracuse, N.Y., December, 1990).

Von Althen is of the opinion that, at least in conventional hardwood plantations, fertilizing at the time of planting should be avoided since it may actually do more harm than good by increasing weed competition (Von Althen, 1976). On the other hand, Blankenhorn *et al.* (1986) found that fertilization only improved the height growth of hybrid poplar when it accompanied poor weed control. They concluded that good weed control may preclude the need for expensive fertilization.

Lothner (1986) presents an interesting analysis of the economic effect of fertilizing SRIC plantations at various times in the rotation. He concluded that the later in the rotation, and the less frequently one fertilizes while still achieving a certain gain in yield, the better will be the economic value of that fertilization. He attributes this to the compound interest charges associated with carrying the fertilization cost to the end of the rotation.

Notwithstanding the specificity of fertilizer needs depending on the site, clones and management regimes, we have chosen to include a cost for fertilization in our economic analysis in recognition that fertilization will be necessary to maximize yields and assure sustainability. The literature was again consulted to determine a range of rates and their associated costs.

Frappier *et al.* (1990) used the following fertilizer regime for the production of Jerusalem Artichokes as an energy biomass crop. They proposed applying $N-P_2O_5-K_2O$ at the rates of 90-50-50 kg/ha. To achieve this they used 0.26 Mg/ha ammonium nitrate (34-0-0). This cost

\$283/Mg in 1988 which was equivalent to \$73.58/ha [\$80]). The phosphorus and potassium were applied as mixed fertilizer (0-20-20) at a rate of 0.25 Mg/ha. These materials cost \$263/Mg or \$65.75/ha [\$72]. The total cost for materials in 1990 Canadian dollars was approximately \$150/ha.

Lothner (1986) assumed a rate of nitrogen application of 112 kg/ha N in the form of urea (46-0-0). This cost \$74/ha for materials [\$120] and \$50/ha [\$80] for application by helicopter for a total cost of \$124/ha [\$200].

It has been suggested that the fertilization rate for corn is also appropriate for SRIC biomass plantations (Blankenhorn *et al.* 1986; Perman, 1985). Since fertilizer needs can be expected to be very site specific, this strategy was used here to provide a reasonable indication of the cost of fertilization. Hope *et al.* (1989) used application rate for N-P₂O₅-K₂O of 127-55-28 kg/ha for silage corn and 156-55-28 for grain corn in Ontario. The cost for these materials in 1989 Canadian dollars was \$96/ha and \$104/ha [\$100 and \$110], respectively. According to Burgess and Wind (1989), the custom rate for ammonium nitrate application in 1988 was \$19/ha [\$21] and for dry fertilizer it was \$11/ha [\$12]. Using this scenario, the total cost for fertilization would be \$243/ha/application.

In Manitoba, Kyle and Therrien (1991) suggested N-P-K for corn at a rate of 101-45-45 kg/ha, at a cost of \$37.37-\$22.95-\$13.05/ha for materials. According to Alberta Agriculture (1990), ammonium nitrate costs approximately \$8.65/ha to apply. The application of dry fertilizer would cost approximately \$5.17/ha in Alberta (Alberta Agriculture, 1990) and \$4.97/ha in Saskatchewan (Saskatchewan Agriculture, 1990) for an average of about \$5.00/ha. If the costs of materials are added to the application costs, this fertilization regime will cost \$87/ha/application.

Perman (1985) did not provide many details of fertilizer prescriptions other than to say that energy forests require about the same fertilization as corn. He indicated that the annual "fertilizing" cost was \$114/ha (\$US 1985) [\$193/ha]

Pfeiffer and Cozzarin (1990) proposed applying the N-P-K at a rate of 100-80-100 kg/ha. The total cost for materials was \$212.70/ha/harvest and the cost for the application was \$73.53/ha/harvest. They note that this was for three years only (10 year hybrid poplar rotation). This would translate to \$95/ha/application for materials and application.

The differences in the various costs appear to be a function of different application rates illustrating the site specificity of the cost of fertilizer input. We used a range of fertilization costs of \$100 to \$200/ha/application.

3.5.2 Irrigation

While some of the highest biomass yields have been reported under irrigation, the added economic and energy costs of this treatment negate any advantage offered by the higher yields (Cushman and Ranney, 1982; Hansen, 1983; Blankenhorn *et al.*, 1986).

Hansen (1983) discusses the possible negative effect of irrigation on tree growth by increasing disease incidence. He points out that this is probably a very minor effect since the duration of leaf wetness will likely not exceed that which might be expected from rain. He suggests that if irrigation is to play a role in SRIC it will have to be by bringing previously unproductive land into a productive state or by reducing the risk due to crop failure involved in SRIC production on some sites.

Because of the high financial and energy costs associated with irrigation, we have chosen not to include this operation in our economic analysis.

3.5.3 Weed Control

Post-planting weed control was considered to cost \$30-\$40/ha based on the costs for chemical weed control in the site preparation phase quoted above. The need for post planting weed control would depend on the initial spacing which would also affect the rotation or cutting cycle. For the purposes of our cash flow analysis, we assumed that weed control would be required in the first half of each rotation. For example in a four year rotation, herbicides would be applied in the first and second year after planting and in the two years following each harvest.

3.6 Harvesting

Ellefson *et al.* (1987) point out that the lack of cost efficient harvesting systems, and storage and handling systems can be expected to act as a deterrent to the expansion of wood energy alternatives. The development of suitable systems can be expected to reduce this deterrent and improve the cash flow picture for energy biomass production.

The costs associated with the harvesting, chipping, drying and storage of energy biomass are somewhat more difficult to determine since the parallel between SRIC and agriculture for these operations is often less obvious. Similarly, the use of associated costs from conventional forestry may give an indication of what may be expected in SRIC with relatively long rotations (i.e., 10 years). However, site and crop conditions may differ sufficiently to make a direct comparison suspect. Such a comparison in shorter rotations may be even less appropriate. A number of prototype biomass harvester have been developed, but again little information appears to be available with respect to the operating costs connected with these machines

When considering very short rotations (three years and less) the custom has been to use cost figures for forage harvesting. Pfeiffer and Cozzarin (1990) suggest that this may result in

an under-estimation of costs since biomass harvesting costs will likely be higher than for corn silage owing to increased labour costs because of a slower field working rate.

Harvesting accounts for a major proportion of the total production costs for SRIC biomass. Based on a 4 year rotation, 10,000 stools per ha, mean annual increments of biomass (MAI) of 12.5 ODT/ha and a 2% real discount rate, Lyons (1988) estimates that harvesting and delivery costs would account for 51% to 73% of the discounted biomass production costs. This is supported by Mitchell (1988), and Ranney *et al.* (1988). Johnson and Erickson (1987) put the proportion of the total costs at 25%.

Sensitivity analysis indicates that not only do harvesting storage and transportation contribute a large proportion to production costs, but relatively small changes in these inputs result in large changes in the production costs. On the other hand, production costs are relatively insensitive to changes in the costs of site preparation, planting and management (Perlack *et al.*, 1985)

The Department of Engineering of Loughry College, Cookstown, Northern Ireland is currently developing a coppice harvester (Loughry Coppice Harvester or LCH) under contract to the Department of Forestry, University of Aberdeen (for more details See Appendix C). J.B. Hudson of the Wood Supply Research Group (WSRG), University of Aberdeen has provided the results of some preliminary trials using this harvester to cut two-year-old willow coppice. Bundles were forwarded to a landing for air drying using a tractor mounted buck-rake. A summary of the associated costs are presented in Table 6. Based on these results a harvesting costs (excluding chipping) of \$28 to \$62/odMg can be expected. These values are approximately equivalent to \$790/ha.

Blankenhorn *et al.* (1986) considered two harvesting strategies for their hybrid poplar system (2100 sph). The harvesting and baling strategy involved cutting and crushing the trees followed by field drying. The second system involved a simultaneous harvesting and chipping

Table 6. Harvesting and forwarding costs for two-year-old willow biomass using the Loughry Coppice Harvester. (Personal Communication: B. Hudson, Aberdeen University February, 1991).

Site Class (odMG/ha/yr)	6	7	10	12	15
Yield (odMg/ha)	12	14	20	24	30
Felling and Bundling Costs (\$/odMg)	45.21	36.18	25.87	21.56	17.24
Forwarding Bundles to Landing (\$/odMg)	17.26	16.08	13.77	12.52	11.02
Total Harvesting Costs (\$/odMG)	62.47	52.26	39.64	34.08	28.26

of the biomass. Their estimated cost for the harvesting and baling system was \$373/ha [\$631] or \$11.39/odMg [\$19] based on 33 odMg/ha. This included harvesting, baling, loading and unloading. For the harvesting/chipping system, the total cost per ha for all phases except hauling was \$844/ha [\$1,428] or \$28.78/odMg [\$44].

Based on actual costs using a modified International Harvester PTO powered corn binder (as described by Johnson and Erickson, 1987), Sibal (1987) estimated the cost of harvesting and binding three-year-old coppice at \$142/ha [\$212]. At 33 odMg/ha estimated yield, this translates to a cost of \$4.30/odMg [\$6.42].

Using the productivity of the FB7, harvesting cost of \$24 (US 1985)/Mg [\$40] may soon be reduced to \$14 to \$16 [\$24 to \$27/Mg] (Ranney *et al.*, 1988; Golob, 1986).

Strauss and Wright (1990) suggest a cost of \$20/odMg [\$23] for harvesting. This is consistent with the SEK 100/odMg [\$21] cost associated with harvesting *and chipping* using the Swedish SEM biomass harvester (Sennerby-Forsse, Appendix D). Dr. Arno Strehler, who is developing a coppice harvester/chipper in Germany, has indicated that he expects

harvesting/chipping costs to be approximately 50 DM/odMg [\$38] (personal communication A. Strehler, Technical University of Munich, February, 1991).

Based on the above figures, we have used a range of harvesting costs (excluding chipping) of \$10 to \$60/odMg. The reporting of harvesting costs on an odMg basis without indicating the associated yield/ha implies that harvesting costs will increase as yields increase. The general consensus is that harvesting costs are area based and so should be constant regardless of the biomass yield. Consequently, the cost per odMg decreases as yield increases. For the purpose of our cash flow analysis we have chosen to estimate harvesting cost on an area basis and the range used was \$215 to \$1,000 per ha. These values are either taken directly from the literature reported above, or they are values reported on an odMg basis and converted to an area basis using the corresponding yields. If corresponding yields were not reported, an average of 48 odMg/ha (12 odMg/ha/yr on a four year rotation) was used.

Another cost which can be attributed to harvesting is that associated with the loss of material during this phase of the operation. Strauss and Wright (1990) suggested a 85% net delivery of yields. Blankenhorn *et al.* (1986) estimated a fibre recovery of 90% in their study. Pfeiffer and Cozzarin (1990) quote experience in the U.S.A. and Sweden which indicates that feedstock losses due to handling and processing will be in the order of 0.5%. We have considered this factor to be accounted for in our cash flow analysis by presenting the results for a range of biomass yields.

3.7 Chipping

Hazenstab *et al.* (1987), in dealing with conventional logging, found that chipping at the stump appeared to be more economical than chipping at the landing, and is comparable to chipping at the mill. Johnson and Erickson (1987) felt that, for trees with diameters less than 7.6 cm, the most cost effective process would be to harvest and chip in one operation as this would reduce labour costs. Foody (personal communication: Pat Foody Sr., Iogen/Techtrol,

January, 1991) is of the opinion that chipping should be done as a separate operation to take advantage of the desirable drying characteristics of the harvested but unchipped biomass.

Research in the U.K. has taken a similar course because of potential problems associated with the storage of chips with high moisture content as outlined under the section on drying and storage. Researchers in Sweden (Appendix D), Italy and Germany (Appendix C) do not, however see these as a problem and have developed systems which harvest and chip at the same time.

Blankenhorn *et al.* (1986) estimated that the chipping phase of their harvesting/chipping operation cost \$104/ha [\$176] or \$3.16/odMg [\$5.33] based on an average yield of 33 odMg/ha.

Sibal (1987) put the cost of chipping three-year-old coppice, using a Morbark Super Eager Beaver whole tree chipper at \$223/ha [\$334] or \$6.76/odMg [\$10]. Iogen (1990) indicated that "Morbark" put chipping costs at \$7.50/odMg and point out that this is consistent with the range of costs reported by Golob (1986).

Mitchell *et al.* (1989b) put the average cost of chipping at £3.51/green Mg [\$8] (based on 46 % MC_{wet} basis). This can be converted to £6.56/odMg [\$15]. These data were based on trials in which four to six-year-old willows were chipped using a truck mounted Siba drum chipper with a grapple feed. Using a tractor mounted Scan chipper the cost, including labour, ranged from £13 to £17/green Mg [\$30 to \$39]. Most of this higher cost is associated with labour. The authors argue that if the tractor mounted chipping is done with labour as an opportunity cost then this system may be viable for small scale operations.

We used a range of chipping costs of \$5 to \$15/odMg.

3.8 Drying & Storage

"The greatest problem at this stage in the fuel pathway is the limited harvest window and the subsequent need for storage (and the associated biomass losses and costs). As much as 3%/month can be lost in dry biomass weight due to wood decomposition, according to studies evaluating chip piles." (Ranney, *et al.*, 1988)

The relationship between moisture content and calorific value is discussed on page 44. Certain problems can be associated with chip piles with high moisture content (greater than 30% MC_{wb}) including a substantial losses of dry matter as stated above; the danger of spontaneous combustion (Thornqvist, 1988); and health hazard to workers resulting from fungal spores (Jirjis, 1988).

Field drying of bundles until July or August has resulted in moisture contents (wet basis) of 32% to 33% (Lyons *et al.* undated). According to Blankenhorn *et al.* (1986) moisture content of less than 20% after crushing and field drying for two days have been recorded. These authors quote studies which indicate that 90% of any reduction in moisture content will occur within 6 to 8 weeks of storage. They also noted research which indicated that biomass stored in bundles suffered less deterioration than that stored in chip piles.

The modification of chips may improve their storage and handling characteristics. Steklenski and Haygreen (1987) compared the economics of using chips and densified wood pellets for direct combustion. They found that pellets have a reduced energy cost, primarily due to the improved storage and handling properties of the densified pellets. Actual chip costs were \$22.50/Mg (1987 U.S.) [\$34] and pellets were \$54.43/Mg [\$82].

A system for the passive drying of energy chips is under investigation in Italy and is briefly described in Appendix C.

We have not included any direct costs in our economic analysis for biomass drying and storage. We have assumed that chips will not be delivered until one year after harvesting and the cost of this delay is reflected in the cash flow analysis.

3.9 Transportation

As stated above, Pfeiffer and Cozzarin (1990) suggest that Domtar considers the production of pulp mill feedstocks using SRIC to be profitable and that this is in part due to the fact that they can produce the material close to the mills and thus reduce transportation costs. By having SRIC plantations located close to conversion facilities and the energy markets, chips from this source will be able to compete more favourably with biomass from forestry residues, since the latter will often have high transportation costs associated with them.

Some of the transportation costs reported in the literature are summarized in Table 7. The figures reported are generally for haul distances in the order of 40 km. Frappier *et al.* (1990) based their figure on those reported for transporting agricultural crops in the Province of Quebec. They used the same value for the western Canadian provinces.

Pfeiffer and Cozzarin (1990) present various costs for different type of highways and for haul distances up to 50 km and from 50 km to 100 km. The values reported here are an average for the various types of roads, up to 50 km. The average cost for hauls between 50 and 100 km is \$0.19/Mg/km.

We have used a range of \$0.15 to \$0.25/odMg/km in our analysis.

4 SRIC YIELDS

In many economic analyses, production costs or net profits have been shown to be very sensitive to variations in biomass yield (Bergusson, 1987; Hansen, 1988; Rose *et al.*, 1981). For

Table 7 Summary of costs associated with the transportation of biomass from the plantation to the conversion facility.

Source	COST/Mg/km	
	Reported	1990 Can.\$
Blankenhorn <i>et al.</i> , 1985	US\$0.15	0.25
Frappier <i>et al.</i> , 1990	Can\$0.14	0.14
Golob, 1986	Can\$0.19	0.22
Perlack and Ranney, 1988	US\$0.10	0.17
Perman, 1985	US\$0.10	0.17
Pfeiffer and Cozzarin, 1990	Can\$0.25	0.25
Sibal, 1987	US\$0.17	0.25

example, Strauss and Wright (1990) describe a scenario involving a commercial sized *Populus* plantation using discounted cash flow. The trees were planted at a density of 2100 sph. Their sensitivity analysis indicated that plantation yields have the greatest impact of any factor in determining the final cost of the output. "If, for example, the 6th year MAI [mean annual increment] was reduced by 25% to 12 Mg(od)/ha/yr, production costs would escalate by 32% to \$21.98/Mg(od). In contrast, a 25% increase in production to 20 Mg(od)/ha/yr would decrease costs by over 20%."

While recognizing a lack of hard information with respect to biomass yields based on actual large scale plantings, Lyons (1988) indicates that yields in Europe have been as high as 16-18 ODT/ha/yr. He goes on to point out that economic analyses have used more conservative values of 10-14 ODT/ha/yr.

Pfeiffer and Cozzarin (1990) suggest that 15 odMg/ha/yr should be considered the norm for yields from agricultural land. Ranney *et al.* (1988) are of the opinion that through clonal

selections and the careful matching of these clones to sites, it may be possible to get 20 to 30 Mg/ha/yr. Mitchell (1988) considers a likely range of 10-20 odMg/ha/yr to be possible "once the right matching of species to sites has been achieved".

At the present time however, "representative productivity rates from marginal agricultural land in eastern North America are more on the order of 7 to 16 Mg/ha/yr" (Ranney *et al.*, 1988). Based on economic analyses, these authors state that 20 odMg/ha/yr is the current break-even rate. This estimate is based on present "off-the-shelf" harvesting and handling equipment, a 15% profit margin, a rotation age of 5 years or more and annual land costs of \$80/ha."

Strauss and Wright (1990) quote studies in which 15-20 odMg/ha/yr are considered to be attainable goals for SRIC and point out that actual results (aged 3 to 4 years) from commercial-sized plantations in the North Central United States are following a growth curve which confirm this potential yield.

Hansen (1988) cites progress in increasing hybrid poplar yields in Eastern Ontario. Initial harvests of 10-year-old field plantations yielded about 2 Mg/ha/yr, which is considered to be comparable to natural stands in North America. Subsequent harvests yielded 2.9 Mg/ha/yr at 6½ years with a projected yield of 3.8 Mg/ha/yr at 10 years of age. Other 6-year-old plantations have projected yields of 3 to 5 Mg/ha/yr at rotation (10 years). According to Hendry (1990) some of the most recent harvests of hybrid poplar in Eastern Ontario indicate MAIs of 2.2 to 2.8 odMg/ha/yr. This is based on a harvest of 40 ha with a 12 year rotation. Chips were blown into a van and weighed at the mill, and consequently this yield could be considered operational for these clones growing on these sites. It should be kept in mind, however, that these yields are from widely spaced plantations not intended to maximize biomass yield. Plantations with narrower spacing (1.5 m x 1.5 m) have predicted yields of 8.4 Mg/ha/yr (Hansen, 1988).

According to Hansen (1988), "... the range of assumed yields for the best-case economic assessments is 7.2 to 11.2 Mg/ha/yr." While these yields did not give what he termed favourable economic returns, they were marginally profitable in 3 out of 4 cases. The author considers these the minimum necessary for positive economic return and calls them "required yields". He is of the opinion that these required yields exceed the presently available field yields [of poplar in Eastern Ontario] by 2 to 3 times but are close to the projected yields from field plantations. The required yields are only half of the current small-plot yields, consequently Hansen feels that these required yields (7 to 11 odMg/ha/yr) are reasonable estimates of potential SRIC field yields.

An exceptionally high yield of 27.8 Mg/ha/yr was recently reported in Washington (Heilman and Stettler, 1985) from new improved hybrids grown in a favourable environment. While yields this high may be reduced considerably when grown in plantations, they do serve to illustrate that breeding and selection can produce clones with very high yields and that it may be necessary to establish these clones on better sites in order to maximize their potential.

Johnson and Ericksen (1987) noted that while yield information from field-sized plots indicated that SRIC yielded two to three times that of average natural stands, these same yields were considerably lower than those recorded for small plots. This possible over-estimation of biomass yields is frequently pointed out as a short coming of the yield information which is currently available from small experimental plots consisting of only a few trees. Extrapolation of these values to indicate yields from large plantations may not be appropriate (Cannell and Smith, 1980; Hansen, 1988; Zavitkovski, 1981).

Hansen (1988) suggests the differences between record yields and field yields may be due in part to shortened rotations ("often only 2 to 5 years") increasing the chance that some plots will have their entire rotation in a period of better than average growing conditions resulting in higher yields. This does apply to crops with rotations of 10 years but is not the case with mini-rotation crops such as willows which may in fact be harvested within this range of 2 to 5 years.

These short rotations make it possible to base yield estimates on a complete rotation - something rare in the field of temperate forestry!

Cannell and Smith (1980) and Zavitkovski (1981) cite the importance of the unrepresentative competition which exists in plantations consisting of many small plots of very diverse genetic structure, as contributing to high yields in small-plot data. The excellent growth of a particular clone may reflect the poor growth of neighbours rather than the genetic superiority of the high yielding plants. When the latter are grown in larger plots or production plantations, competition between ramets of the same clone will be much higher as these individuals will be obtaining their resources from the same niche. Poor distribution of irrigation water was also cited as a possible cause of reduced yields in more homogenous, large plots or plantations (Zavitkovski, 1981).

Cannell and Smith (1980) suggest that to avoid edge effects, border rows comprising the same genetic material as found in the test plot, should have a width at least equal to one quarter the height of the measured trees.

4.1 The relationship between spacing and yield

Cushman and Ranney (1982) noted that most of the results from the U.S. Department of Energy, Short Rotation Woody Crops Program indicate that, for tree-form species, the highest average annual yields result from stands which have their average annual productivity peaking at 8 to 10 years and these stands will likely have densities of approximately 1,100 to 4,400 stems per ha.

Berguson (1987) tested the effect of planting density on the biomass yields of hybrid poplar clones. The author concluded that densities of between 33,000 and 18,000 stems per ha will produce higher yields, more quickly than will densities of 10,000 stems per ha. Johnson and Erickson (1987) were of the opinion that a planting density of 10,000 sph was most likely

appropriate for rotations greater than three years but also noted that their harvest data indicated higher yield at higher densities.

While increased planting densities will often result in higher yields they will, however, also result in higher establishment costs. Dutrow and Saucier (1976) considered sycamore at 6,700 sph and 4,500 sph on 3, 4 and 5 year cutting cycles to be economical, but at closer spacing (27,000 sph and 13,500 sph) the additional yields per ha did not offset the added cost of planting at these densities. According to Lyons (1988), sensitivity analysis based on a 4 year rotation, 10,000 stools per ha, yield levels of 12.5 ODT/ha and a 2% real discount rate, longer rotations (5 to 6 years) and lower planting densities were optimal, even when lower yields were considered.

Woodfin *et al.* (1988) state that, for single stem harvesters, spacing will not affect harvesting costs which is more a function of tree size. They point out, however, that this cost will rise as a percentage of the total cost if the cost of planting (i.e., stock, labour, equipment, etc.) is reduced.

Ek *et al.* (1983) found that the number of coppice sprouts was directly proportional to the planting density. Their projections and those of Zavitkovski (1983) suggest that the initial productivities of hybrid poplars are higher at narrower spacings, but the wider spacings are comparable at greater ages. According to Stettler and Heilman (1980), yields of *P. trichocarpa* were significantly higher at closer spacing (0.3 x 0.3, 0.6 x 1.2, 1.2 x 1.2) in the first 4 years, but this effect disappeared after 8 years of growth. These observations suggest that the closer spacings encourage an earlier occupation of the site, but once the crowns have closed spacing has little effect on the overall productivity. This suggests that once crown closure is achieved (everything else being equal), the productivity for a plantation is restricted by the photosynthetic area available regardless of the number of stools on which it is supported. Consequently, it

would appear that the primary role played by plant spacing with respect to yield relates to its impact on the rotation or cutting cycle.

4.2 The effect of rotation length on yields

According to Stettler and Heilman (1980), yields of *P. trichocarpa* for one harvest at 8 years were about 40% higher than the total of 2 harvests at 4-year rotations. Preliminary results from a test near Bristol, England indicate that the yield from two, 2-year rotations of Bowles hybrid willows (unfertilized) are not significantly different from those for a single four-year rotation (personal communication: Justin Ford-Robertson, University of Aberdeen, February, 1991). Wright (1988) found similar results when she summarized 48 trials from the U.S. D.O.E. Short Rotation Woody Crops Program. In 83% of the cases, two 2-year coppice rotations yielded less than a comparable 4-year rotation. In 27% of the cases the 2-year rotation system yielded 50% less than the single rotation.

The length of the rotation will directly affect the time-cost of the investment and the rotation length, the strategies associated with many operations, and consequently the costs of those operations. For example, DeBell and Harms (1976) suggest that the transition between two totally different harvesting systems probably occurs at a rotation of three years, with a modified silage harvester used for rotations under three years and a scaled down felling, bunching, skidding, chipping operations used for rotations over that age.

Woodfin *et al.* (1988) collected yield information from a large SRIC database maintained by the U.S. D.O.E. Short-Rotation Woody Crops Program. From this database they selected results based on tests which had grown beyond the culmination of their current annual increment (CAI). They selected as the appropriate rotation the age at which the CAI had peaked. This resulted in a collection of 26 data points with planting densities ranging from 772 sph to 191,276 sph on which a simple regression of rotation (age at maximum CAI) vs density was performed. The resulting relationship was :

$$R = 16.97 - 2.844 \text{ LOG } D$$

Where R represents the rotation age in years and D represents the planting density in stems per ha. This relationship explained 83% of the variation in the optimum rotation. The authors point out that this is a good fit considering the diversity of the tests examined and the fact that they ranged from Alabama to Wisconsin. The authors do not indicate what species were represented in the 26 tests used in the regression. The results of this regression are summarized in Table 8.

DeBell and Harms (1976) suggest that (for hybrid poplars) there may be some merit in combining rotations of different length. The first rotation could be three years to provide fibre and revenues as early as possible and to stimulate coppice growth. Subsequent rotations could be 4 to 10 years to provide larger diameter material. The importance of stimulating the vigorous coppice growth by cutting-back the plants after the first year's growth has been noted above.

Not only must the length of the rotations be considered, but the number of rotations will have an effect on the economic viability of the plantation system. Dutrow and Saucier (1976) considered the effect that the number of coppice rotations per planting would have on the profitability of silage sycamore for pulp production. As one might expect they found that profits increased with the number of coppice rotations, presumably since establishment costs were spread out over a larger number of harvests.

Table 8 Estimated rotations (maximum CAI) for various planting densities based on the regression developed by Woodfin *et al.* (1988).

Density (sph)	Rotation (years)
1,000 - 2,000	8
3,000 - 4,000	7
5,000 - 10,000	6
11,000 - 24,000	5
25,000 - 40,000	4

4.3 Reported Yields

Some reported yields have already been cited in the text above. A further indication of some of the yields which have been achieved using SRIC follows.

The breeding programme at the Forest Genetics Laboratory, Faculty of Forestry, University of Toronto has produced over 300 clones of hybrids of various North American willow species. Clonal screening trials were established in 1987 at four locations: at the Ontario Ministry of Natural Resources nursery at Kemptville, Ontario; near Maple, Ontario; at the Petawawa National Forestry Institute and near Syracuse, New York. The primary purpose of these trials was to identify superior clones based on relative performance on a number of sites. With the exception of the Syracuse test, all were planted at a spacing of 1 m x 0.5 m resulting in a nominal density of 20,000 sph. The Syracuse test was established in conjunction with the College of Environmental Science and Forestry at the State University of New York, Syracuse. In this case the density was approximately 111,000 sph.

All trials, except for Syracuse, were harvested during the winter of 1990/91 based on two-year-old coppice (on three-year-old roots), and the dry weights of all ramets of all clones were determined. The harvest at Syracuse was of one-year-old coppice (on four-year-old roots). The final results of this assessment including statistical analyses will be reported elsewhere when completed, only indications of average dry weight yields are included here. It should be noted that these test, as clonal screening trials, consist of small plots (four trees per plot). It is hoped that the establishment of larger scale plantations currently under development by the Forest Genetics Laboratory will make it possible to determine how the yield estimates quoted here are correlated with production scale plantings. Note also that the harvest of two-year-old coppice was for research purposes and is pre-mature for a stocking of 20,000 sph - a production harvest would have occurred after four or five years growth. At Syracuse, with a stocking of 111,000 sph, production harvests would occur annually. Therefore, our most recent harvest at this site represents a production harvest.

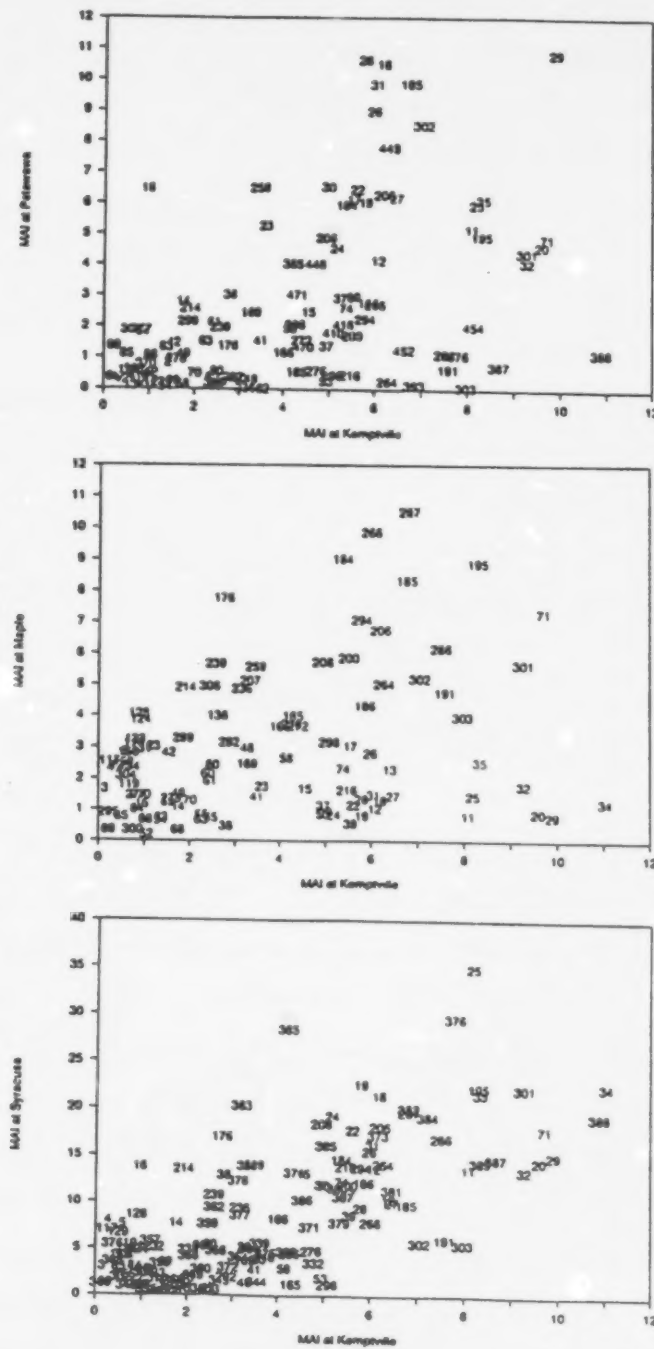


Figure 1 Graphical representation of average yields of all clones. (Kemptville, Maple and Petawawa yields based on a harvest of two-year-old coppice - mid-point through the rotation)

The yields for each clone averaged over all blocks and replications within blocks are presented graphically in Figure 1. Note the dramatic range in yields across all clones. The important aspect to note from these figures is that, while the range of yields are very similar, the clonal rankings are different between sites as indicating the fact that clones which do well on one site do not necessarily rank highly on other sites. This illustrates the importance of the role played by genotype x environment (GxE or clone x site) interaction in determining biomass yield. To tap this source of variation, extensive clonal testing will be required to determine which clones will produce best on a particular site.

Certain clones appear to do relatively well on all the sites on which they were tested (note that not all clones are replicated on all sites). For example clone 34 (*S. eriocephala* x *S. eriocephala*) was the second best clone at Kemptville and Petawawa producing in excess of 11 odMg/ha/yr. This clone was the fifth best at Syracuse producing greater than 22 odMg/ha/yr at higher planting density. Similarly, clone 29 (also *S. eriocephala* x *S. eriocephala*) was third at Petawawa, sixth at Kemptville and 37th at Syracuse. In both cases these clones were not planted at Maple.

These yields should be considered conservative since the coppice harvested at Kemptville, Maple and Petawawa was only two-years-old; some two years younger than the rotation usually prescribed for a density of 20,000 sph (see Table 8). Consequently, it is reasonable to assume that the MAIs reported here may be underestimates of the clones potential since the maximum photosynthetic area will not have been established prior to harvesting. In the forestry vernacular, the crop will not have captured the full productive potential of the site. Also, logistics prevented optimal weed control at these sites, probably reducing yields.

At Syracuse, however, because of the higher density planting, the site has been captured after one year's growth. The yields at Syracuse, therefore, are a much better indication of the potential of the clones.

It should also be noted that the yields reported here are the average for each clone. The productivity of many ramets and blocks exceeded the average indicating the clonal potential.

In an earlier report on the productivity of similar material Mosseler *et al.* (1988) indicated that 15 to 20 odMg/ha/yr could be expected from unselected clones established at a density of 20,000 sph and grown on a rotation of 1 to 3 years.

Robertson (1990) reported that stool beds of various species of willows at Pasadena, Newfoundland regularly produce 25 to 28 odMg/ha/yr. One stand planted at a density of 25,000 sph and consisting primarily of *Salix alba*, yields 60 odMg/ha after 3 years growth (MAI of 20 odMg/ha/yr) following the first coppicing.

A summary of yield figures for a number of production trials in Sweden is presented in the sub-contractors report (Appendix D). These figures are for: those plantations with a root age of at least three years; plantations which have been cut back or harvested at least once prior to assessment; planting densities were not exceeding 30,000/ha; and only large plots. In all cases the best results from a range of fertilizer tests are included and in the case of clonal screening trials, only the five best results are reported. The survey of farmers involved in energy biomass production yielded a total of 1,345 results, only 61 of which met the above-mentioned criteria for inclusion in the report. The average MAI from these was 12 odMg/ha/yr with a wide range in values from 3.5 odMg/ha/yr to 23.0 odMg/ha/yr. Production results from eight high priority willow clones exhibited an average MAI of 10.2 odMg/ha/yr and a range of 1.9 to 19.7 odMg/ha/yr based on 107 reported results.

The variation in the productivity of the various plantations reported in this Swedish survey is very striking and underlines the considerable potential to improve the average MAI from 12 odMg/ha/yr towards the higher levels of 23 odMg/ha/yr through clone/site matching and cultural techniques. In addition, continued breeding and selection will contribute to higher yields. While the Swedish programme is one of the largest and most advanced with respect to

the production of willow energy biomass, it is important to note that most of the results are from plantations less than six-years-old. Consequently, continued research will undoubtedly result in a better understanding of clone x site and clone x cultural treatment interactions making these gains in yield possible.

Under the U.K.'s Department of Energy's Renewable Energy Research and Development Programme, the Forestry Department of Aberdeen University has established a number of willow and poplar trials to examine technical aspect of SRIC energy biomass production. Mitchell *et al.* (1989a) report early progress in these studies. The yields reported in this summary are for the first year's growth and as such do not reflect the potential yields of coppice production.

Kopp reported that the average annual yields from their woodgrass trials using five willow and one poplar clone was 9.2 odMg/ha/yr in the fertilized plots and 7.7 in the unfertilized plots. The values are averaged over three annual harvests (i.e., rotation of one year) and excludes growth in the year following planting (personal communication: R.F. Kopp, College of Environmental Sciences and Forestry, State University of New York, Syracuse, N.Y. December, 1990).

At the present time, production yields in the order of 10 to 15 odMg/ha/yr appear to be reliably achievable. Considerably more work must be done to identify superior clones, to address the issue of GxE interaction, to determine appropriate herbicide regimes, to determine optimum fertilization schedules, etc. It seems reasonable to assume that advances in these areas coupled with advanced generation breeding will improve biomass yields considerably. While the progress made in willow breeding at the Forest Genetics Laboratory has indicated that substantial gains in biomass yields are possible, one must keep in mind that these results are the product of a single round of breeding and selection with no fertilization and less than optimum weed control.

The potential of tree improvement leading to increased yields is well documented. Zsuffa (1983) summarized yield increases resulting from breeding programmes for a variety of tree species. For example, loblolly pine yields have quadrupled, Eucalyptus yields have increased by a factor of 2.5, and hybrid poplar productivity has nearly tripled as a result of tree improvement.

Yield improvement in tree species is demonstrating the same success as seen in agricultural crops. For example, between 1950 and 1980, wheat yields in the U.K. and the Netherlands doubled (Buringh, 1987).

The most intensive, and well-funded, willow breeding programme is being conducted by the Department of Forest Genetics, Swedish University of Agricultural Sciences in Uppsala. During the first three-year phase of this programme (1986-1989), Gullberg (1989) reports a doubling of biomass yields compared to those clones currently in production. Further increases are expected as work continues.

More work is necessary to understand how yields in large plantations will compare with those from smaller experimental plots. Work is progressing in this area in various parts of the world as breeding programmes move into this next important phase. The sustainability of biomass yields is also an important factor which will hinge upon our understanding of such complex aspects of SRIC as nutrient cycling, insect and disease epidemiology and plant resistance, species and clonal variation in coppicing ability over long periods of time, etc. Since larger scale plantations have only recently been established, it will be sometime before the sustainability of these system can be confirmed. It should be noted, however, that basket willow plantations in the United Kingdom have been harvested annually for at least 50 years with no signs of declining vigour (personal communication: Mr. Ken Stott, Long Ashton Research Station, Bristol. February, 1990).

In the previous sections we have presented the various factors which appear to have an impact on the production cost of energy biomass from SRIC and we have discussed how these factors influence biomass yields and *vice versa*. Our next objective is to consolidate this information to arrive at an estimate of the expected costs associated with the production of energy biomass.

5 COST OF PRODUCTION ANALYSIS

We have shown that considerable variation exists with respect to actual or estimated input costs and expected yields. Obviously, the input costs will vary according to which estimates are accepted and what management regimes are used. Yields will be governed by the same management regimes, site conditions, climatic conditions, the species and clones employed for a given site and strategy, etc. Because of this complexity, it would be pointless to try to arrive at a single production cost and suggest that this was the figure to quote to prospective growers. The best that is possible at this stage in the development of the SRIC concept is to provide a range of production costs based on a range of input costs and potential yields.

5.1 Methods

A range of costs for each operation in an array of biomass production scenarios was determined from the literature and other sources. A summary of these ranges is presented in Table 9. The total cost of production was estimated based on a discounted cash flow analysis for which a Lotus 1-2-3 spreadsheet was developed for this study. The validity of the spreadsheet was tested using other cash flow programmes and by calculating NPVs for test cases by hand. The NPV is the sum of all revenues discounted to the present minus the sum of all costs discounted to the present, or:

$$NPV = \sum \frac{\text{revenue}}{1+i^n} - \sum \frac{\text{cost}}{1+i^n}$$

where: i = the discount rate (0.5);
 n = the number of years to discount.

Table 9 A summary of the ranges for various costs used in the cash flow analysis.

Operation	Range of Cost (1990 \$Can.)	
	LOW	HIGH
Land Rent (/ha/yr)	50	150
Herbicide (/ha)	65	85
Plough (/ha)	20	80
Disc, 2 passes (/ha)	20	80
Cultivate (/ha)	10	25
Cuttings (/thousand)	25	225
Planting (/thousand)	15	50
Fertilize (/ha/applic.)	100	200
Weed Control (/ha/applic.)	30	40
Cut-Back (/ha)	250	500
Harvest (/ha)	215	1,000
Chip (/odMg)	5	15
Haul (/odMg/km)	0.15	0.25

A spreadsheet provided by Energy, Mines and Resources Canada was also reviewed.
 See Appendix G.

Because of the importance of planting density on the rotation length and subsequently on the cash flow for a plantation operation, we have considered three densities; 5,000, 10,000 and 20,000 stools per ha. The rotations associated with these densities have been estimated using the relationship developed by Woodfin *et al.* (1988) and described on page 32 of this document and in consideration of those rotations being used in various SRIC programmes throughout Europe and North America. We have chosen to use nominal rotations of 6, 5 and 4 years respectively, for the three densities. It must be kept in mind that rotation length / planting density relationships require further study to determine optimal productivity and economics in production plantations.

In our scenarios we have assumed that continued breeding will result in new clones being available on a regular basis. To take advantage of these new clones as well as the advantage of a number of coppice rotations, we have assumed that each plantation will be replaced after approximately 18 years. The actual life of a particular plantation is determined by the number of complete cutting cycles or rotations which can be achieved in this time.

We have estimated the cash flow for each of these planting density/rotation situations using the low and high values from Table 9, resulting in a total of six plantation scenarios.

Actual yields will be a function of a number of factors and their interactions. We have initially estimated the cash flow for each plantation scenario using an MAI of 12 odMg/ha/yr based on the results reported above. A more meaningful value for this analysis is the break-even MAI, that is the mean annual yield which is required to produce an NPV of 0, given specific production costs and a specific selling price for the product (biomass). The break-even MAI was estimated by running each scenario for a number of MAIs (5, 10 and 20 odMg/ha/yr) to determine the NPV for each. The equation for the linear relationship between NPV and MAI was determined based on the slope of the line and the y-intercept. Using this relationship, the MAI which would result in an NPV of 0, or the break-even MAI, was determined. This procedure was carried out for a range of product values (\$20, \$40 and \$60/odMg).

The importance of product price, in this case the biomass feedstock, has been shown to have a significant effect on the rate of return associated with energy biomass production through SRIC (Hoganson and Lothner, 1988; Rose *et al.*, 1981). The cost of coal is often used as a shadow price for biomass energy because of its long term availability and relatively low cost to purchase and convert to electricity. According to Ontario Hydro (personal communication: Ontario Hydro Public Relations Department, November 15, 1990), in 1989 the utility used the amounts of coal in its thermal generating plants summarized in Table 10.

Table 10 Amounts and costs of various classes of coal purchased by Ontario Hydro in 1989.

Coal Type	Amount Purchased (10 ⁶ Mg)	Cost (10 ⁶ \$)	Energy Content (GJ/Mg)	Cost/GJ (\$)
U.S. Bituminous	7.3	390	30	1.78
Western Canadian Bituminous	3.2	255	25	3.19
Western Canadian Lignite	1.7	57	16	2.10

From these figures, the utility purchased a total of 12.2 million Mg of coal at a total cost of \$702,000,000. The weighted average cost per GJ is \$2.19 (1989). This value inflated by 4.9% would be equivalent to \$2.30.

The higher heating value of wood appears to vary little between species and is generally considered to be approximately 19.8 GJ/odMg (Bowersox *et al.*, 1979; Krigstin, 1985; Pfeiffer and Cozzarin, 1990). If we assume this energy content, then the value of the biomass for electricity generation (based on the cost of coal) would be \$45.54/odMg.

This value is based on oven dry feedstock; because of the high energy and financial cost associated with drying biomass to 0% MC, it is more appropriate to consider the energy at a moisture content which could feasibly be delivered. Such a value will be somewhat less than that noted above. In direct combustion, some of the energy derived must be used to vaporize the moisture in the fuel. As a result, while the higher heating value of woods appears to vary only by a small amount, the moisture content of the wood may affect the net energy available in a particular feedstock. This moisture is that present in the fuel at the time of utilization and that derived from the combination of hydrogen and oxygen in the combustion process (Hakkila, 1989; Butner *et al.*, 1987). The effect of moisture content on the heating value of fuels can be seen from the following relationship (Butner *et al.* 1987; Hakkila, 1989):

$$\text{LHV} = \text{HHV} - (0.2205 \times H) - (2.45 \times \text{MC}_{\text{wb}} \div (1 - \text{MC}_{\text{wb}}))$$

where:

LHV = the lower heating value or the energy content of a Mg of wet wood;

HHV = The energy content (GJ/odMg) of dry wood as determined by calorimetric measurements;

H = the hydrogen content of the wood (w/w); and

MC_{wb} = the moisture content of the wood on a wet weight basis.

The first quantity subtracted from the HHV represents the heat lost in driving off the moisture created during combustion and the second represents the moisture present in the wood before combustion. This value represents the energy content of the wood with a particular moisture content, expressed on an oven dry basis (Hakkila, 1989). To convert this to a green weight basis the LHV should be multiplied by the proportion of dry wood in the fuel or $1 - \text{MC}_{\text{wb}}$. The relationship between heating value and moisture content is illustrated in Figure 2.

In the U.K., air drying of bunds from the time of harvest to July or August can result in a MC_{wb} of approximately 35% (Mitchell *et al.* 1990). Iogen (1990) assessed the drying characteristics of willow "cuttings". They found that air drying for five months after winter harvesting could reduce moisture content to as low as 10%.

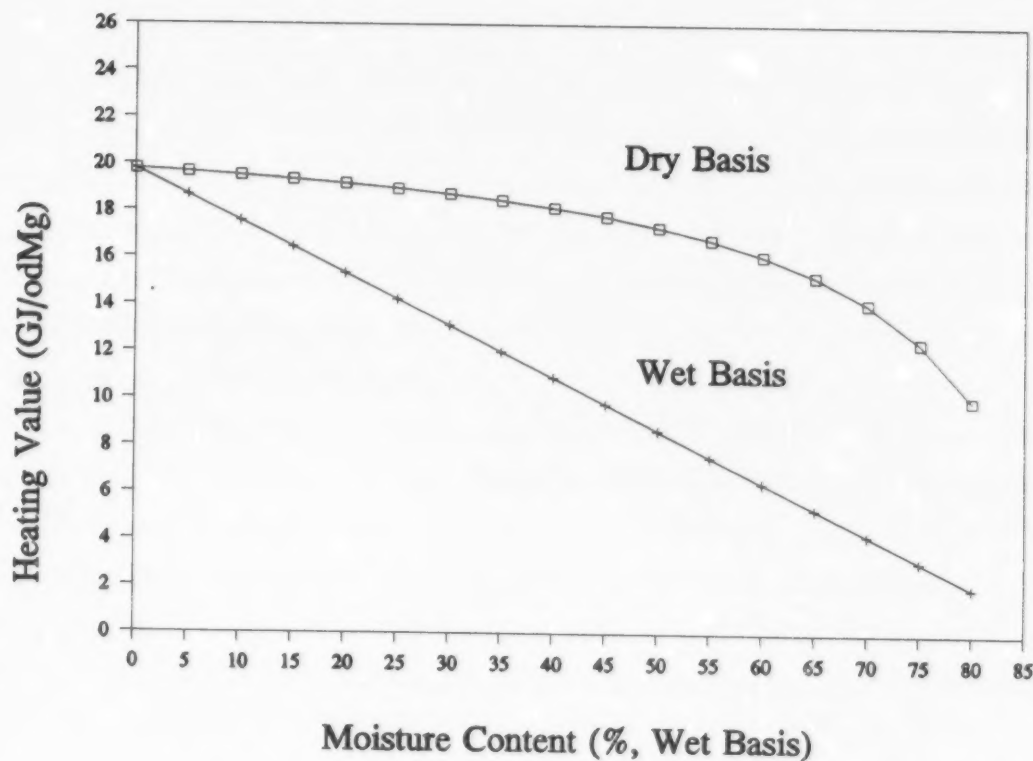


Figure 2. The relationship between heating value and the moisture content of wood.

Based on the above relationship, air dried biomass ($MC_{wb}=35\%$) would have an energy content of 18.5 GJ/odMg and undried feedstocks (assuming $MC_{wb}=50\%$) would have an energy content of 17.3 GJ/odMg. Using the value of \$2.30/GJ derived for coal, air dried biomass would have a value of \$42.55/odMg and green biomass would have a value of \$39.79/odMg.

The Grenville Christian College in Brockville, Ontario has heated its facilities (13,000 m² or 140,000 ft²) using a wood waste combustion system for a number of years. Mr. John Childs (personal communication, February 5, 1991) of that institution has reported that they used 933 odMg of bark waste from a local mill during the 1989/90 heating system. The average delivered cost of this feedstock was \$35.19/odMg, which could be considered a shadow price for SRIC biomass in the Brockville area.

Using coal costs as a shadow price for energy biomass does not recognize differences in conversion efficiencies using the two feedstocks (Lyon, 1986), nor does it consider the fact that the use of coal may have environmental costs associated with it which are seldom considered when determining the true value of this method of generating electricity. Biomass also has potential as a feedstock for liquid fuels such as ethanol and methanol, as well as chemicals (Iogen, 1990; Lora and Wayman 1979; Wayman, 1989; etc.). Many of these conversion technologies are not as mature as the use of biomass to produce electricity by direct combustion, which is a proven technology (Pfeiffer and Cozzarin, 1990). Consequently, it is more difficult to quantify the value of the feedstock for such processes.

Chum *et al.* (1985) and Wayman and Parekh (1990) illustrate the value of co-products associated with many conversion processes and suggest that in some cases the co-products may command a higher price than the primary product.

We have assumed a nominal product price of \$40/odMg for each scenario. Because of the many variables mentioned above, there will be a wide range of values associated with biomass depending on its end-use. A complete investigation of these factors was considered beyond the scope of this study. Consequently, a procedure similar to that described for estimating the break-even MAI was used to determine a break-even selling price for a given scenario and a given MAI.

In a discounted cash flow analysis, the net present value (NPV) will be affected by the interest rate used. Lothar *et al.*, (1986) applied a real discount rate of 4%. Pfeiffer and Cozzarin (1990) quote Kula (1984) who states that the real discount rate for Canada has been estimated to be 5%. This discount rate is consistent with that used by others (Blankenhorn *et al.*, 1986; Ek and Brodie, 1975; Gardner *et al.*, 1983; Perlack *et al.*, 1985; Strauss and Wright 1990) and consequently, was adopted for this study.

Using the above values as inputs we have used the spreadsheet to determine the; present or discounted value of the costs (PVC) associated with all aspects of producing the biomass; the discounted value of all biomass sales or revenues (PVR); the net present value (NPV); the internal rate of return (IRR) and the benefit/cost ratio (B/C). The PVC and NPV are estimated on a per ha basis and on the basis of an odMg, which is determined by dividing the per ha value by the discounted yield.

Because of the wide range in costs and values reported in the literature, selecting these values for the cash flow analysis has associated with it a considerable degree of uncertainty. To assess the impact that changing these values would have on the NPV, a sensitivity analysis was carried out. The model was run for levels of each of the cost/revenue items at levels 10% higher than reported values, providing a range of NPVs within each harvesting scenario. The rate of change in the NPV associated with a change in the input variables provides an indication of the sensitivity of the model to each variable.

The true value of this procedure is to compare the relative sensitivity of the variables. Having identified these, it will be possible to prioritize the factors in terms of the research and development efforts which will return the greatest improvements in the economic situation for energy biomass production.

5.2 Results and Discussion

The results of the cash flow analyses for each scenario are presented in Appendix F.

Table 11 summarizes the result of the cash flow analyses. As was expected, when the cash flow for plantations with increasing planting density but fixed MAIs were considered, the economic outlook was more favourable at the lower planting densities. Obviously, if one could produce 12 odMg/ha by planting only 5,000 stools per ha, there would be little advantage in terms of the NPV or IRR in planting more trees to produce the same 12 odMg/ha/year. The longer rotations assigned to the lower planting densities used in this analysis did not result in the cost associated with these rotations negating the advantage of the lower establishment costs.

All planting densities at the low cost level yielded positive NPVs; the scenario using 20,000 sph and the low costs level was just above the break-even status assuming an MAI of 12 odMg/ha/yr and a product value of \$40/odMg.

Table 11 Summary of the results of the cash flow analysis for biomass production at various planting densities and cost levels. See Appendix G for details.

Density (sph)	Rotation (yrs)	Cost Level	PVC (\$/odMg)	NPV (\$/odMg)	IRR	B/C
5,000	6	LOW	31.40	8.60	11.2	1.27
10,000	5	LOW	33.18	6.82	9.7	1.21
20,000	4	LOW	38.11	1.89	6.2	1.05
5,000	6	HIGH	87.86	-47.86		0.46
10,000	5	HIGH	149.22	-103.72		0.39
20,000	4	HIGH	173.37	-132.24		0.30

At the high costs level, the situation is somewhat different. Even at the lowest planting density with its relatively low establishment costs, large increases in yields and/or product values must be realized before this scenario will break-even. For example, at the lowest planting density, an MAI of 20 odMg/ha/yr a selling price for the delivered biomass would have to be in excess of \$62.72/odMg just to recover the production costs of delivered feedstocks. At a planting density of 10,000 sph an MAI of 20 odMg/ha/yr would require a break-even product value of \$72/odMg. However, this value is similar to that currently paid for hardwood pulp chips in Ontario.

These analyses have considered the range of values only. We reconsidered these values for each of the input costs to develop a "current scenario" for Canada. For this case, we chose a land value of \$75/ha. This amount is in the order of that reported for agricultural land in Ontario currently used for crops such as hay and forage but not for the highest value crops in the most productive regions of the province. It is also consistent with values reported for the prairies. Site preparation costs were based on the custom farmwork rates reported from three provinces, since these can be assumed to be as close to actual costs as can be expected. These values are as follows: Herbicide and spraying, \$85/ha; ploughing, \$44/ha, discing, \$25/ha; and cultivation, \$21/ha. It should be kept in mind that a subsequent sensitivity analysis revealed that variations in these costs had relatively little effect on the cash flow. Based on the most frequently reported values for the cost of fertilization, we have chosen a value of \$150/ha. This may be slightly low for central and Eastern Canada and slightly high for the West. A cutting cost of \$50 per thousand and a planting cost of \$28 per thousand were used. Weeding costs were set at \$30/ha. Again, the sensitivity analysis indicated that this component contributed only a small amount to the overall cash flow. A cutting-back cost of \$375/ha was included. A cost of harvesting of \$800/ha was selected based on the reports using the Loughry Coppice Harvester (LCH) and those reported from Sweden (Appendix D). Similarly, chipping and transportation costs were set at \$10/odMg and \$0.20/odMg/km. These figures are summarized in Table 12.

Table 12 A summary of the inputs and outputs for the "current" scenario for energy biomass production. Also shown are the inputs for both unsubsidized and subsidized future scenarios.

Operation	Range of Cost (1990 \$Can.)		
	Current	Future	Subsidized
MAI (odMg/ha/yr)	12	20	20
Product Value (\$/odMg)	40	45	45
Land Rent (/ha/yr)	75	75	0
Herbicide (/ha)	85	45 ¹	45 ¹
Plough (/ha)	44	27 ¹	27 ¹
Disc, 2 passes (/ha)	25	15 ¹	15 ¹
Cultivate (/ha)	21	13 ¹	13 ¹
Cuttings (/thousand)	50	50	0 (subsidy)
Planting (/thousand)	28	21 ²	21 ²
Fertilize (/ha/applic.)	150	75 ¹	75 ¹
Weed Control (/ha/applic.)	30	20 ¹	20 ¹
Cut-Back (/ha)	375	0 ¹	0 ¹
Harvest (/ha)	800	600 ²	600 ²
Chip (/odMg)	10	8 ²	8 ²
Haul (/odMg/km)	0.20	0.20	0.20
Subsidy (/ha/yr for first 5 yrs)	0	0	300
Production Cost (\$/odMg)	60.76	34.57	22.43
NPV (\$/ha)	-2,133.00	1,777.42	4,529.04
Benefit/Cost ratio	0.66	1.30	2.01

¹ Farm labour instead of contractor

² 25% increase in efficiency

Given the potential values for biomass as determined above, we are of the opinion that \$40/odMg is a reasonable value and an MAI of 12 odMg/ha/yr appears to be currently attainable.

The cash flow for a scenario involving these costs, revenues and biomass yield was determined as before, using a planting density of 10,000 sph and a 5 year rotation. The total production cost was \$60.76/odMg resulting in a negative NPV (-\$2,122.39/ha) and a benefit/cost ratio of 0.66. The break-even analysis indicated that, at the current product value of \$40/odMg, an MAI of 23.3 odMg/ha/yr would be required for this scenario. This figure is within the range of some clones currently in production. At 10 odMg/ha/yr the product would have to sell for \$69.31/odMg - again, close to the current price for hardwood pulp chips in Ontario. This scenario is not economical at this point, given the conservative values used in this scenario. However, increasing the MAI to 20 odMg/ha/yr would result in a break-even selling price of \$43.66/odMg, a value very close to the product value assumed here without considering environmental costs. This is quite encouraging since the productivity of 20 odMg/ha/yr is commonly recognized to be attainable with improved clonal material and silvicultural techniques.

The relative proportion of the total cost of producing the delivered biomass attributable to each cost item for this scenario is presented in Figure 3. Note in particular that fifty-two percent of the total discounted costs per ha for this scenario was attributed to harvesting, chipping and storage. The question now arises as to which input items should receive the greatest attention with respect to improving the cash flow, or in other words, what is the sensitivity of the NPV to changes in each of the cost or revenue items?

This question was addressed using the "current scenario" described above, for the 10,000 sph scenario. The change in the NPV resulting from a 10% increase in each cost or revenue item or the MAI was determined and the results summarized in Table 13. An increase of 10% in the value of the biomass (i.e., from \$40/odMg to \$44/odMg) would increase the NPV by over \$400/ha. While this is a substantial improvement in the NPV, it would not be sufficient to make

Table 13 Sensitivity analysis based on 10,000 sph. Values represent the change in Net Present Value per ha (NPV) (in \$/ha or %) resulting from a 10% increase in the cost or revenue item or the MAI, assuming all other factors remain constant.

Cost or Revenue Item	Change in NPV	
	\$/ha	%
Product Value	+409	+19.30
MAI	+225	+10.6
Harvest	-143	-6.7
Chipping	-102	-4.8
Land Rent	-89	-4.2
Transport	-82	-3.9
Fertilization	-61	-2.9
Planting	-50	-2.4
Cutting-back	-36	-1.7
Cuttings	-28	-1.3
Weed Control	-13	-0.6
Pre-Plant Herbicide	-8	-0.4
Ploughing	-4	-0.2
Discing	-2	-0.1
Cultivation	-2	-0.1

this scenario reach the break-even point. This does serve to indicate that producing higher valued products than feedstocks for direct combustion will play an important role in determining the economic viability of SRIC energy plantations. Since our estimated product value was based on current coal costs, this value would increase if the environmental costs of burning coal or other fossil fuels were included in their value per Mg or GJ. Interestingly, recent changes in

the tax laws in Sweden have increased the costs of fossil fuels to a point where biomass and peat are now the cheapest sources of energy (Appendix D).

By increasing the MAI from 12 to 13.2 odMg/ha/yr would result in an increase in the NPV of \$225/ha or 10%. This illustrates the importance in continued R&D in the fields of tree improvement and silviculture.

The next greatest improvement in the cash flow would result from a reduction in the costs of harvesting and chipping. As has been indicated earlier, these costs and that due to transportation account for a very substantial part of the total discounted cost of feedstock production. The relative proportions for this scenario are presented in Figure 3. Note that the combined cost of harvesting, chipping and transport account for over 50% of the total cost. A reduction in the cost of harvesting of 10% would increase the NPV by \$143/ha. A similar reduction in the cost of chipping and transport would further improve the NPV by another \$102/ha and \$82/ha, respectively.

Reducing the cost of land rent by 10% will improve the NPV by \$89/ha or 4%. It should be kept in mind that this should not be achieved by using land of poorer quality as this could reduce the MAI and result in a net decrease in the NPV.

Fertilization costs also appear to play a moderate role in determining the NPV. By reducing the fertilization cost by 10%, the NPV would increase by \$61/ha. Obviously this must not be achieved at the cost of productivity or sustainability of the system. The use of sewage sludge or the development of clones with a high nutrient-use efficiency could provide a means of reducing this cost.

The sensitivity analysis indicated that a reduction in the planting costs (primarily the cost of planting but to a lesser extent the cost of cuttings) will have a considerable impact on the cash flow for the scenario under consideration here. A 10% reduction in the total establishment cost

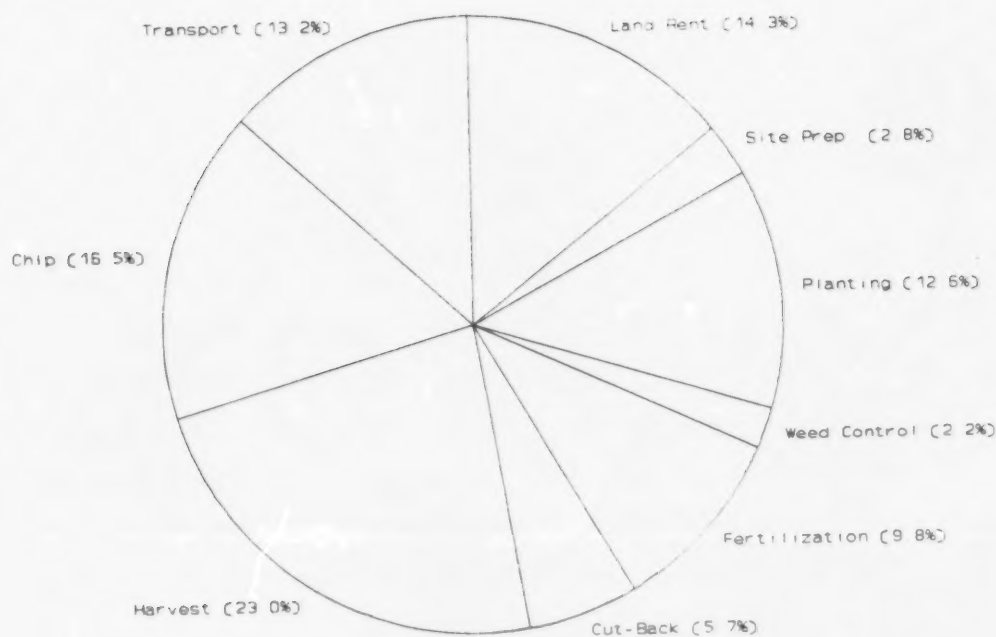


Figure 3 The relative proportions contributed by the various cost items, to the total discounted cost of production.

(stock + planting cost) will increase the NPV by \$78. Higher planting densities will, of course, incur higher costs. One approach to reducing the high costs of planting stock reported by some authors has been suggested by researchers at the WSRG of the University of Aberdeen. They have suggested that a landowner should spread his/her establishment costs over a number of years equal to the planned rotation length. In other words, if 20 ha are to be planted and managed on a four year cutting cycle, five ha should be planted each year. In so doing, a continuous income will be eventually ensured since five ha will be harvested each year. However, an additional advantage is possible using such an approach. It is suggested that cuttings be made from the material produced when cutting-back the previously planted area. In

so doing, it may be possible to reduce substantially the cost of cuttings since the whips must be cut to stimulate coppice.

A commercial nurseryman involved in cutting production in the U.K. (Appendix C) has indicated that a production (excluding harvesting and transportation of whips) of 1,000 cuttings per person-hour can be achieved without mechanization. Since cuttings would be made in the winter, labour costs could be considered as 0 based on the opportunity costs which would further reduce the cost of cutting production.

We see two possible drawbacks to this approach. Firstly, plant breeder's rights might eventually make it illegal to multiply clonal material. Secondly, while annual harvesting would improve the cash flow, there may be some loss in the economy of scale if a contract harvester is hired to harvest only a proportion of the total planting on a site each year rather than to harvest the complete area less frequently. Notwithstanding these possible short-comings, this approach seems quite interesting and may ultimately play a role in reducing the cost of establishment of biomass plantations.

Unfortunately, the NPV appears to be relatively insensitive to the cost factors over which the farmer may have the greatest control (e.g., site preparation, weed control, cutting-back). This is not to say that these factors will not have an impact on the economic viability of the operation. Effective weed control including site preparation will have a direct impact on the MAI of the plantation. A relatively few dollars spent on controlling weeds from the earliest stages of plantation management may affect the growth of the plants to such an extent as to make the difference between a financial success for failure.

Having reviewed the current situation, two possible future scenarios were reviewed:

In the first scenario, the product value increases to \$45/odMg, and the yield improves to 20 odMg/ha/a. Instead of contract labour, the farmer provides his own labour, thus reducing

many operational costs. For planting, harvesting and chipping, a 25% decrease in cost is assumed due to an increase in machinery efficiency. Land rent and haulage costs remain the same as in the current scenario. All costs are listed in Table 12.

Using these figures, the production costs become \$34.57/odMg resulting in an NPV of \$1,777.42 and a cost/benefit ratio of 1.30. This scenario is profitable.

In the second future scenario, all figures remain the same as those just noted, with the following exceptions: Idle land is used, therefore land rent is 0. Cuttings are provided free-of-charge for plantation establishment. A subsidy, similar to the set-aside programme in the U.K., is included - \$300/ha for five years. See Table 12.

This scenario is more profitable than the former: Production costs are \$22.43/odMg with an NPV of \$4,529.04. The benefit/cost ratio has risen to 2.01.

The use of farm labour, an increase in productivity, and more efficient machinery will make energy plantations profitable. Subsidies, such as providing planting stock at no charge and establishment incentives, will increase profitability.

For comparison purposes, other scenarios were investigated. Outputs from cash flow analyses and a graphic summary of the relationship between MAI and production costs are in Appendix F.

6 SUMMARY AND CONCLUSIONS

6.1 Status

Considerable progress has been made in various aspects of the production of energy feedstocks through SRIC. The initiations of large-scale plantation programmes however, will be contingent upon such ventures being recognized as economically viable enterprises.

Economic assessments of SRIC have been reported using a broad range of scenarios. This report has consolidate much of this data and has revealed that, while most reports recognize the same cost factors, a wide range in the magnitude of many costs exists.

Most reports indicate that at the present time, the production of energy feedstocks through SRIC is at or slightly below the break-even point, without direct or indirect subsidies. By using the low-end of the range of costs reported, an interest rate of 5% and a product value of \$40/odMg, a plantation established at 20,000 sph and yielding 12 odMg/ha/yr would break-even. While higher densities appear to result in somewhat higher yields, their main function appears to be in the reduction of the rotation or cutting-cycle and thereby reducing the time before the operation pays back the initial investment. The high input cost analyses would require very high MAIs or product values to break-even.

In addition to the high and low costs figures derived from the literature and discussions with researchers in the field, a third set of costs figures was developed in this study to represent the "current" situation for Canadian SRIC plantations. This analysis indicated that some further progress must be made in reducing costs and/or increasing the product price or biomass yields if landowners are to be encouraged to produce energy biomass. A sensitivity analysis indicated that the most important factors are the product value, the MAI (odMg/ha/yr) and the cost of harvesting and delivering chipped biomass to the conversion facility. A reduction in the planting cost and the cost of fertilization will also improve the economic outlook.

Reports in the literature; up-to-date results provided in the sub-contractors reports from Sweden and the U.K.; and current results from trials established by the Forest Genetics Laboratory indicate that biomass MAIs of approximately 10-15 odMg/ha/yr are currently and reliably possible. Other reports indicate that SRIC plantations have already achieved in excess of 20 odMg/ha/yr. The wide range of values reported from replicated trials indicate that most clones tend to be adapted to particular sites. Consequently, the careful matching of clones to sites will ensure higher yields. The wide range in reported yields also suggests that genetic gains through breeding and clonal selection could be substantial. For the most part, the yields reported here are from the first round of breeding and selection. Advanced generation breeding, coupled with more information *vis à vis* GxE interactions, ecophysiology, insect and disease resistance, stress tolerance, carbon allocation, etc. can be expected to improve yields towards 20 odMg/ha/yr and beyond.

The analyses conducted here assumed a product selling price of \$40/odMg. This was based on a shadow price for coal to Ontario Hydro. Since North American coal reserves appear to be substantial, it is unlikely that this cost will increase much in response to changes in the supply and demand status. However, concern is being expressed world wide over the environmental impact of fossil fuel use and nuclear power generation. If the environmental cost of burning coal is added to the shadow price, the economic picture for energy biomass will be much brighter than that depicted here. For example, the report that changes in the energy tax structure in Sweden have resulted in biomass and peat becoming the cheapest sources of energy in that country (Appendix D) indicates the impact that this aspect of biomass production can have on the overall economic outlook for energy forestry. Notwithstanding this important aspect, the costing of environmental degradation and similar externalities was beyond the scope of this study. Consequently, we have used a product value of \$40/odMg but wish to emphasize that this should be considered conservative since the cost of coal used to derive this shadow price is "subsidized" by the environment.

Lothner (1988) describes various types of economic project appraisals. These include financial, economic, social and environmental appraisals. He points out that in most cases only financial appraisals are done for SRIC programmes from the viewpoint of a profit-oriented entity or firm. This was the approach adopted for this study since it was considered most appropriate for the objectives under consideration. While financial appraisal may indicate that a programme is only marginally profitable under a given set of constraints, the overall benefit to society that the programme may impart may become more apparent following economic, social and environmental appraisals. If these value are recognized, the cash flow analysis presented here should be reconsidered with appropriate subsidies to the grower to encourage him/her to invest in SRIC in spite of the cash flow constraints noted above.

As already mentioned, the co-operation of researchers in all areas of biomass production and conversion is essential to improve the economic outlook. Tree breeders are needed to improve and maintain high yields in the face of potential insect and disease problems; silviculturalists will have to address the question of optimum planting density and rotation length, weed control, fertilization, and the standardization of crop parameters etc.; and engineers will have to develop more cost effective harvesting methods and conversion processes.

As demonstrated here and elsewhere, land costs and yield are important to the economic viability of energy biomass. However, little appears to be known about the distribution of land based on tenure, purchase or rental cost, location, estimated establishment costs and potential yields. With the advent of Geographical Information Systems (GIS) it is now possible to incorporate extensive data into complex models which could be used to optimize plantation programmes aimed at minimizing transportation costs while maximizing yields. Related site information will be essential if variation associated with GxE interactions is to be tapped by the proper matching of clones to sites.

There exists in Ontario alone potentially 400,000 ha of farmland which is erodible (personal communication: Harold Rudy, Ontario Soil and Crop Improvement Association,

January, 1991) and, as such, should be removed from annual agricultural production, usually to be used for grazing, forage production or left idle. SRIC could serve as an alternative land use in situations such as these. While complete weed control is required in the early stages of plantation establishment, considerably less tillage would be required over the life of a biomass plantation than with corn or soybeans (once in the life of a twenty year plantation programme vs annually with most agricultural crops). If wind erosion was a concern, appropriately situated strips of uncut trees could be left at the time of each harvest to protect the soils until the soil was again protected by coppice regrowth. The suitability of SRIC to erodible soil conditions must be further investigated before this potential source of land with a low opportunity costs can be tapped.

As mentioned before, breeding and selection programmes must be expanded to achieve the required annual yields. Such programmes must include clonal testing on a variety of sites involving an array of management regimes to determine GxE interaction and to identify the clones best suited for various situations.

Growth and sustainability will be affected by most aspects of trees improvement and silviculture. However, knowledge of nutrients cycling in energy plantation systems will play a major role in this aspect of improving the long term economic viability of energy production through SRIC. The use of sewage sludge may provide one cost effective means of increasing yields by fertilization while providing for the disposal of waste. As with all aspects of SRIC, the economic costs and benefits of such programmes must be factored into any such programme.

This analysis and others indicates that the production of energy feedstocks through SRIC appears to be currently just below the break-even point. However, when one considers that development of this land use system is relatively young; product values used were conservative; environmental costs associated with alternative sources of energy were not considered; and all scenarios were free of direct or indirect subsidies; the development of SRIC for the production of a renewable source of energy on an environmentally and economically sustainable basis does

appear to be within our reach. To achieve this objective will require a co-ordinated research effort and a market for the product but most of all the political will to achieve the goal.

6.2 Potential

There is great potential for the production of woody biomass in Canada as a feedstock for energy and other products:

- Breeding programmes and improved cultural techniques will increase yields.
- Production costs will be reduced by the development of more efficient machinery and cultural techniques.
- The price of woody biomass should increase to its real value. Compared with the combustion of fossil fuels, woody biomass is, at worst, environmentally neutral. If, as currently in Sweden, a "carbon tax" is applied to fossil fuels, woody biomass will become a much more economically attractive fuel. Also, biomass is the potential feedstock for a variety of high-priced products and co-products.
- If the production of environmentally positive and/or neutral fuels is considered important by government, incentives (subsidies) should be provided to encourage energy plantation establishment.
- As the economics of energy plantations improve, trees will become a viable alternative crop for farmers.

6.3 Future Work

While the results of these economic analyses and those reported elsewhere indicate that the unsubsidized production of energy biomass through SRIC is nearing the break-even point, additional research and development is needed. Some important areas for further work are:

- continued, and more intensive, breeding and selection to develop high yielding, stress tolerant clones with uniform growth habit;
- development of cost efficient harvesting systems;
- characterization of promising clones with respect to nutrient-use efficiency, site requirements, and pest/disease resistance;
- continued research into the optimization of planting density, rotation length, and cultural techniques;
- determination of the extent, productivity, location and tenure of land potentially available for SRIC production;
- investigation of the potential for the use of erodible land for SRIC production;
- establishment of demonstration plantations to provide reliable figures on production yields and costs;
- progress in the improvement of economics and yields of energy plantations should be monitored.

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APPENDIX A

Currency conversion factors based on IMF inflation data.

Currency conversion factors based on IMF inflation data

Year in which cost was reported	Currency in which cost/revenue reported			
	Canadian \$	U.S. \$	Swedish K	U.K. £
1971	3.7127	3.7202	0.7647	9.4957
1972	3.4031	3.3881	0.7143	7.9556
1973	3.1192	3.1061	0.6771	7.2161
1974	2.8590	2.8339	0.6945	6.6554
1975	2.6206	2.6635	0.6074	5.3897
1976	2.4020	2.4241	0.5874	4.1268
1977	2.2016	2.4086	0.5158	4.5908
1978	2.0180	2.3934	0.5572	4.8693
1979	1.8497	2.1606	0.5211	4.8052
1980	1.6954	2.0255	0.4632	4.8308
1981	1.5540	1.8429	0.3308	3.5162
1982	1.4244	1.7511	0.2401	2.8272
1983	1.3104	1.6306	0.2038	2.3654
1984	1.2480	1.6491	0.1834	1.9071
1985	1.2104	1.6916	0.2221	2.4435
1986	1.1798	1.6287	0.2388	2.4015
1987	1.1521	1.4975	0.2561	2.8026
1988	1.0994	1.4029	0.2396	2.4264
1989	1.0490	1.2797	0.2236	2.3645
1990	1.0000	1.1652	0.2063	2.2360

APPENDIX B

The relationship between planting density and costs using regression analysis on the data of DeBell and Harms (1976).

DeBell and Harms (1976) provided cost data for materials and planting for 5 planting densities. We determined the relationship between planting density and costs using regression analysis with these data. The input data are presented in Table 1.

Table 1. The cost per hectare for cuttings and planting reported by DeBell and Harms (1976). The values have been converted to 1990 Canadian dollars.

Stems/Ha.	Cutting Costs/ha.		Planting Costs/ha.	
	1975 US\$	1990 CAN\$	1975 US\$	1990 CAN\$
2,990	22.00	58.60	22.50	59.93
4,485	65.00	173.13	27.50	73.25
6,850	49.00	130.51	35.00	93.22
13,455	95.00	253.03	45.00	119.86
26,909	190.00	506.07	65.00	173.13

Regression analyses were performed on the data in Table A-1 resulting in the following relationships:

$$\text{Cutting Cost/ha} = 35.67 + 0.0172 \# \text{ stem per ha.}$$

$$\text{Planting Cost/ha} = 54.27 + 0.0045 \# \text{ stem per ha.}$$

Based on these relationships the establishment costs for various planting densities are presented in Table 2.

Table 2. The cost of planting per hectare and per thousand, for various planting densities based on the regressions performed on the data from Table A-1.

sph	Planting		Cuttings		TOTAL	
	\$/ha	\$/K	\$/ha	\$/K	\$/ha	\$/K
1000	58.81	58.81	52.91	52.91	111.72	111.72
2000	63.34	31.67	70.15	35.08	133.50	66.75
5000	76.95	15.39	121.88	24.38	198.83	39.77
10000	99.62	9.96	208.10	20.81	307.72	30.77
15000	122.30	8.15	294.31	19.62	416.62	27.77
20000	144.98	7.25	380.53	19.03	525.51	26.28

APPENDIX C

A report on a trip to the United Kingdom by W.A. Kenney in February 1991 to discuss the economics of SRIC with the U.K. sub-contractor and to observe a test harvest using the Loughry Coppice Harvester prototype.

**REPORT ON THE VISIT TO THE UNITED KINGDOM
February 12 to 22, 1991**

W.A. Kenney

In February, 1991 the author visited the United Kingdom to confer with colleagues at the University of Aberdeen. Dr. C.P. Mitchell, the leader of the Wood Supply Research Group at that institution was a sub-contractor to the Forest Genetics Laboratory. The visit was planned to coincide with field testing of a biomass harvester being developed in the U.K. This was considered to be particularly valuable since the cost of harvesting, storage and chipping of biomass can contributed between 70% and 80% to the total production cost of woody biomass energy feedstocks.

The following is a brief outline of the activities in which the writer was involved during the visit and some of the more important points raised during discussions.

February 12 to 13

In transit from Toronto to Aberdeen

February 14

This day consisted primarily of discussions about the activities of the Biomass Unit, Wood Supply Research Group (WSRG), Department of Forestry of the University of Aberdeen. Justin Ford-Robertson and Miles Watters gave me an overview of the work that the Biomass Unit has been involved with particularly with respect to the economics of biomass production and harvesting costs. A number of reprints were made available to me and the relevant information has been included in the body of the report of this report.

Mr. Watters has developed a spreadsheet which examines the cash flow for any input harvesting scenario. This is a very comprehensive system which links spreadsheets containing the input data and the cash flow model. As is the case with most economic estimates performed by the group, costs and revenues are estimated on a per GJ basis as well as a per ha or per Mg. The calorific value for the feedstock used is based on an air dried energy values for the wood and not on an oven dry basis as is most often the case in the current literature. This will be expanded upon below.

One interesting approach being considered to reduce the cost of plantation establishment is the spreading out of the planting over a number of years. If, for example, a farmer plans to plant 10 ha of SRIC plantation he may choose to plant only one ha in the first year. In this way, cuttings for subsequent plantings could be obtained from this initial planting thus reducing the cost of purchasing cuttings substantially. A plantation designed in this way would have the added advantage that a proportion of the plantation would be ready for harvest each year, a situation which may improve the cash flow for the farmer. While

this is an interesting concept, I see two possible areas of concern. Firstly, plant breeder's rights may eventually prevent the multiplication of cutting material in this manner. Secondly, while it may be advantageous to harvest a portion of the plantation each year, economy of scale may favour having contract harvesters hired less often for a larger harvesting operation. In other words, how will the cost of moving equipment affect the cost per hectare or Mg of biomass when harvesting only one or two hectares rather than five or ten?

February 15

Barry Hudson provided me with an overview of the forestry situation in the U.K. to serve as a basis for discussions around the use of residues from conventional forestry as energy feedstocks. He described the development of the Loughry Coppice Harvester and the productivity of this machine to date.

The group has developed a harvesting model based on the Microsoft Windows Environment. The Harvesting Decision Support System makes it possible to compare various harvesting options based on their associated energy costs and productivities. A more complete description of the system is provided in Mitchell *et al.* (1990).

During this discussion, the concept of air drying bundles before chipping was discussed. It would appear that the direct chipping of biomass at the time of harvesting may create problems in chip storage. At a moisture content in excess of 50% (wet basis) considerable dry weight loss of chips can occur; spontaneous combustion can result in chip pile fires; and the development of fungal spores may prove to be hazardous to the health of workers. Air drying of bundles from the time of harvest to July or August can result in a MC_{wb} of approximately 35%. Based on the relationship:

$$\text{Calorific Value} = 18.1569 - 0.2064 \times MC_{wb}$$

this results in an energy content of 10.9 GJ/ Mg air dried. This value (or similar ones for conifers) is used in all economic calculations involving costs per GJ for air drying scenarios.

Mr. Hudson re-emphasized the importance of reducing the costs associated with the harvesting, chipping and storage of energy biomass, to the economic viability of biomass energy. With these costs comprising 70% to 80% of the cost of production, biomass energy is "not on" unless these costs can be substantially reduced.

The Wood Supply Research Group uses a feedstock production cost of £2.40/GJ [\$5.38/GJ] as a "sieve" to eliminate production systems which cannot be considered economical under practical considerations [NOTE: This is more than twice the value often quoted as a reasonable shadow price based on coal in the U.S.A. and Canada].

Mr. Hudson is of the opinion that, while NPV and IRR figures from discounted cash flow analyses may suggest longer rotations, wider spacings and higher value crops [i.e. conventional forestry], farmers will most likely favour shorter rotations and therefore closer spacings because of a quicker return on their investment.

Left for Bristol.

February 16

While en route to the harvesting trial at Long Ashton Research Station (LARS), Bristol, Justin Ford-Robertson and I visited Murray Carter's operation in Yorkshire. Mr. Carter produces christmas trees and nursery stock on a fairly large scale and has an extensive stoolbed collection of willows and poplars. He sees his role in the Energy Biomass scene as a producer of cutting stock.

This visit was an excellent opportunity to see an extensive planting of a large number clones and to visually compare their productivity and form. Neil Roberts, Mr Carter's manager (Murray was out of the country), provided some interesting insight into the production of cutting material from the perspective of an experienced nursery manager. Some areas of discussion were weed control, cutting cycles (allow newly planted cuttings to grow for two years before cutting back), productivity of cutting production (1,000 cuttings per person hour can be produced from whips without mechanization).

February 17

Continued to Bristol

February 18

Long Ashton Research Station, Bristol

After assisting with some preparatory work for the harvesting demonstration, I was given a tour of some willow trials on the research station by Rodney Parfitt.

In the afternoon, Ken Stott took me to visit a number of basket willow operations in Somerset. Some of these stool beds have been harvested for many years. One such bed had purported to be 100 years old. However, as Ken pointed out, dead stools are usually replaced with a cutting at the time of harvest so that turnover of the original plantings over a long period of time may be considerable.

We visited a planting of a number of willow clones [and a few poplars] on the Maltby Property near Langport. This test was planted in 1987 and cut back in 1987 and 1988. The trees were planted at a relatively dense 40,000 per ha. Many of the clones exhibited considerable mortality of many of the relatively small shoots from each stool. This may

have been a reflection of the high density. Mr. Stott took considerable time with me to describe the various good and bad characteristics exhibited by each of the clones in the test. Aside from the apparent differences in yield, it was obvious that the form of some clones would have a considerable effect on the ease of mechanical harvesting.

Harvesting of one-year-old basket willow material has been mechanized in some cases using a relatively small, Belgian-designed machine which cuts and bundles. Unfortunately, I did not see the machine in operation.

February 19

The Loughry Coppice Harvester (LCH) was in operation on this day, working in 2-year-old Bowles Hybrid willow. Bundles were removed from the site to a landing where they were to be weighed and stored to examine the effect of field drying. One-half of the biomass will be covered with a porous paper tarpaulin and the other half will be left uncovered to examine the effectiveness of each storage method.

Bundles were moved to the landing using a forwarder consisting of a modified agricultural tractor with a hydraulic grapple and trailer. This system seemed to be quite effective in picking up individual bundles in the field but at the time of unloading it was difficult for the operator to pick up one or two bundles from the bed of the trailer without also closing the grapple on a portion of an underlying bundle. This meant that he had to release the load and reposition the bundles and try again. In some cases, bundles were broken during this process. At this point, I began to question the advantage of actually tying the bundles rather than simply operating the system as a feller-buncher. It is my understanding that the complexity of the bundle tying mechanism has proven to be a considerable challenge in the development of this harvester. In previous tests, bundles were small enough that they could be forwarded to the landing one or two at a time using a buck rake attached to the rear of a farm tractor.

Another apparent incompatibility between the two components of the system arose from the fact that the grapple on the forwarder exerted much more pressure than the packing mechanism on the harvester. Consequently, when a relatively tight bundle was picked up and compressed by the grapple, the twine holding the bundle became slack and some integrity of the bundle was lost. I am not certain how serious a problem this was.

Severing of the two-year-old coppice appeared to be quite effective and for the most part bundling and tying of this material appeared to go relatively well. WSRG personnel were carrying out a time study of the harvesting operation the results of which should be available soon.

Damage to stools appeared to be minimal but stumps seemed rather high to me (± 15 cm). On a few occasions this resulted in the stool being severed at a point below that from which the coppice had sprouted leaving a single large cut surface rather than a number

of small ones. It will be interesting to see how this may affect stool survival and the sprouting characteristics next year. I should point out that this happened only in a very few instances. Mr Henry McLean, designer and builder of the LCH told me that stool damage has always been a concern of those involved in the growing of the willows but he is of the opinion that there has been no apparent evidence of mortality due to this factor over the years that he has been testing the machine. I had the opportunity to briefly observe the LCH working in Ireland in 1988. I believe that stool damage may have been greater at that time than at Bristol during this test. The addition of an automatic saw levelling device may have contributed to this apparent improvement.

The first few days of the harvesting operation enjoyed cool dry weather and the movement of the equipment appeared to do little damage to the site. Towards the end of the week rain softened the ground and some minor rutting occurred. It appeared that much of this was done by the forwarder travelling over the same route a number of times. Extremely high winds eventually made it necessary for the harvester to work in one direction while harvesting the much taller ($\pm 7\text{m}$) 4-year-old coppice. This coupled with a heavy rain resulted in some rutting occurring at the point where the machine turned to make its next run.

We carried out a survey of the harvested area to determine how much residual biomass was left on the site following harvesting and forwarding. This survey excluded biomass on the stump below the line of cut. It did include material left on the stump above the cut line (i.e. sprouts left uncut) and also material left on the ground. Details of this survey will be made available but my impression is that the system is extremely effective in collecting the biomass from this type of site and clonal material.

One interesting observation made was the rooting and successful sprouting of uncut sprouts from the previous harvest. This could be an important consideration as the integrity of rows could be lost if this became extensive, which would hinder the efficient operation of the harvester. If many sprouts with a pronounced basal sweep are present, it might be necessary to manually remove such sprouts once the mechanical harvest is completed. If this only occurs occasionally it will most likely not be a serious problem but it does emphasise the importance of considering crown form in clonal selections.

February 20

Justin Ford-Robertson and I travelled to a new planting at Swindon. Considerable rabbit or hare damage was seen on the newly planted cuttings. Plans are being put into effect to fence the property.

From Swindon we travelled to Swanbourne and a Poplar test (2-year-old) which was to be harvested by the LCH during the following week. At this site we met Barry Hudson and visiting scientists/engineers from Europe: Dr. S. Baldini and C. Baldelli from Italy and Dr. A. Strehler from Germany. These individuals are co-operating with the WSRG and

others in Europe in a network established to coordinate R and D in harvesting, transport and storage of short rotation coppice plantations.

February 21

The meeting with WSRG personnel and the visiting scientists reconvened at LARS. Dr. Martin Nellist (AFRC Engineering, Bedford U.K.) whose specialty is biomass drying, joined the group. In the afternoon I was invited to sit as an observer in a meeting in which progress in the harvesting, drying and storage of biomass was discussed.

At the present time six harvesters are being developed. These include three in Sweden, one in Italy, one in Germany and one in the U.K. (the LCH). An overview of the Italian, German and U.K. systems were presented.

Work on the continent addresses the comminution of biomass at the time of harvesting, where as the U.K. system would involve the field drying of bundles with chipping at the landing some months after harvesting. Part of the difference in approach stems from the high moisture contents found in the biomass in the U.K. As mentioned above, this can result in problems of dry weight loss, spontaneous combustion and the health hazard to workers due to fungal spores which develop in the wet chips. The Italians feel that their climate permits rapid enough drying of the chips (*Robinia* which can apparently be harvested year round) that these problems are not of concern.

Cost and production figures for the Italian machine is not yet available since both are still in the early developmental stages. It was hoped that the Italian prototype will be available for demonstration in May of 1991.

The Italians consider productivity, reducing damage to the soil and preserving the regenerative ability of the stools to be of prime importance in the design of their machine. Their system must be able to operate on slopes. It was pointed out that the LCH would most likely not be able to operate on the slopes often encountered in Italy.

It was pointed out that *Robinia* stools were intentionally damaged and early results suggest that there is no evidence of loss of productivity. The circular saw used in the current design may be replaced by shears since the saw is easily damaged in rough terrain.

The same group in Italy is examining a system for the passive solar drying of biomass chips. A shed (40 m X 17 m X 6 m) open on three sides and with a sand floor has been constructed. Chips are piled in this building ± 3.5 m high and the pile is turned weekly either by tractor or pneumatically. The 1 cm chips are dried from 50% MC_w to 10% in 15 to 21 days using this method. In the discussion that followed, it was suggested that it may be more efficient to blow solar heated air through the chips rather than to move the chips around. Dr. Nellist pointed out that chip size will be important to such an operation with

larger chips allowing greater infiltration of the drying air. Chip size will also be related to the type of combustion system to be employed in chip utilization.

The German prototype uses a chainsaw to sever the tree and the cut stem is elevated in the vertical position to a height of approximately 1.5 m to feed into the chipper. Chips are then blown into an attached or accompanying van.

This system has been designed around existing equipment and will be able to handle first thinnings from conventional forestry as well as coppice. The prime mover is an agriculture tractor (150-200 hp). The chipper head costs approximately 30,000 DM [\$39,000] and the total machine (excluding the prime mover) is expected to cost approximately 50,000 DM [\$65,000]. The equipment is very robust, weighing about 1 Mg and is expected to be able to harvest approximately 1 ha/hr [compare with 1 ha/day for the Loughry Coppice Harvester] on slopes of 6% to 10%. The machine is expected to be ready for field testing during the winter of 1991/92.

The Loughry Coppice Harvester weighs 2.5 Mg and also uses a conventional tractor as the prime mover. The total cost of the harvester (excluding the tractor) will be in the order of £35,000 [\$78,400], or £22.50/productive machine hour [\$52.65]. Notwithstanding the constant forward speed (1m/second and 30 seconds to tie each bundle), production will vary with crop yield. Earlier trials indicate that for two year old willows growing at a rate of 6 odMg/ha/yr, the cost of harvesting and forwarding to the landing would be £27.94/odMg [\$65.38]. If the yield was increase to 15 odMg/ha/yr, this cost could be reduced to £12.64/odMg [\$29.58].

I asked the designers how they would prioritize biomass characteristics in terms of their ease of handling. They all agreed that uniformity was of prime importance and that straight, vertical stems were important.

February 22

The harvesting of two-year-old and four-year-old biomass, and residual biomass assessments continued. The LCH had more difficulty in handling the longer 4-year-old stems since the tying mechanism placed the highest of the three ties near the middle of the bundle. Consequently, some bundles opened up when ejected from the harvester.

SUMMARY

This trip provided an excellent opportunity to obtain up-to-date information with respect to the approach to the economics of biomass production in the U.K. (and, to a lesser extent, the continent). I was introduced to some concepts which had not been previously considered and have been incorporated into the "Economics and Yields of Energy Plantations - Status and Potential". The opportunity to observe the operation of the LCH provided me with considerable food for thought with respect to the economics of harvesting of biomass

and also the implications of clonal selections based on crown form, spacing, rotation length, site selection etc. As is the case with most visits such as this I made a number of valuable contacts which I am sure will contribute to many aspects of the development of our Energy Biomass programme at the Faculty of Forestry.

APPENDIX D

A report by Dr. L. Sennerby-Forsse, Swedish sub-contractor.

SRIC IN SWEDEN - REVIEW OF THE ECONOMICS

Review for EMR/Canada 1990/91

L Sennerby-Forsse

Swedish University of Agricultural Sciences

FOREWORD

The National Board of Energy (STEV) in Sweden in 1985 presented a report "Energy Forestry (1985:9)", a summary and evaluation of research and development about energy forestry in Sweden. The report concluded that fuel from energy forests had the potential to become an economically competitive energy source during the 1990-ties. The report also concluded that the most suitable land for energy forests is farmland located in southern and middle Sweden (latitudes 54-64°).

In 1986 STEV established three large scale energy plantations on farm lands run by the land owners, i.e. the farmers. In total these plantations comprised 500 ha.

In 1988 the Dept of Forestry-Industry-Market Studies (SIMS) at the Swedish University of Agricultural Sciences (SUAC) got the mission to review the economy of these practical scaled plantations, to develop economical profitability calculations and to evaluate the improvement potential for the future.

The goal of the analyses is to show the production costs and the economical potential in relation to other solid fuels and to other ways of using surplus farmland (due to overproduction problems).

The study has a time-frame of 5 years, i.e. it is based on the existing technique, the plant material presently available and management knowledge achieved so far. The plantations are located on good farming land in southern and middle part of Sweden.

This document is a review of a SIMS reports published in this area 1989 (Parikka) and also includes information from Danfors (1990) and Sennerby-Forsse and Johansson (1990).

Since the publication of the SIMS report environmental taxes have been introduced for fossil fuels (1991). These regulations have made domestic fuels (wood and peat) the cheapest energy alternatives in Sweden today and can be expected to have a positive influence on the development of a stronger market for bioenergy fuels within the near future.

SUMMARY

Energy forestry (EF) is characterized by a large establishment cost and small to average annual costs for management. A farmer must therefore be prepared to invest money on a longer than normal period compared to conventional crops and on a shorter than normal period compared to conventional forestry. The largest single costs are harvest and planting, to control these costs are to control the cost development of the whole concept. The profit is mostly influenced by yield and the market price on fuels, these two factors being crucial to the economy. The farmer can make either a self-cost calculation or a subsidy calculation. In the former case the variable costs as well as salary (his/her own), machinery and land rent are included in the calculation. The land rent is estimated and may vary with location and soil quality.

Table 1 Prerequisites for a self-cost calculation

- * Today's cultivation technique (24-year rotation, 6 harvests)
- * Today's machinery
- * Interest 6 %
- * Land rent 500 SEK per year and ha
- * Yield 12 tonnes DM per year and ha
- * No subsidies
- * Fuel price 115 SEK/MWh

In middle Sweden with an expected annual yield of 12 tDM per ha the break-even price on biofuels must be 138 SEK/MWh. Today the price is 115 SEK. In southern part of Sweden the expected annual yields are higher, around 14 tDM per year and ha and the break-even price here is 132 SEK/MWh.

It is evident that the Swedish energy policy has influenced the price relations between domestic fuels and imported fuels. In 1991 new environmental taxes have been introduced for fossil fuels. These regulations have made the domestic fuels (wood and peat) the cheapest energy alternatives in Sweden today.

EF is still in its initial stage, and has a large development potential to lower input costs and to increase yield. The highest improvement potentials are found in:

- * a lower cost of cuttings, due to improved cultivation techniques (from 0.30 to 0.20 SEK/cutting)
- * lower planting costs due to improved machinery (from 5 hrs to 3 hrs per ha)
- * lower harvesting costs due to improved harvesters. Modifying the existing ESM-harvester (lowering the cost from 100 to 90 SEK per tDM) as well as lower chipping and transportation costs (10 % decrease)
- * improved logistics, i.e. lower transport and logistics-costs.
- * new harvesting technique altogether

Using these rather small modifications the break-even price could be lowered to 85-90 SEK/MWh. To this should be added that improved plant material through selection and breeding will increase yields. The conclusion of the study is that if there is a need for EF in the future, as it is an environmentally healthy energy system, rather moderate improvements are necessary to create an economically competitive energy source.

3. METHODS OF CALCULATION.

The economical calculations made are investment calculations for different cultivation scenarios. The costs for EF-fuel delivered at the power plant are compared during different circumstances. The calculations are based on real interest rates, i.e. machinery costs include 12 % interest rate (bank loan rates) and all other factors have an interest rate at 6 %. The profitability of the plantation is judged on basis of net present value 1 (= today's in/output) and the break-even price on fuel 2 (= the price at which the net present value equals 0).

- * n=year
- * S_k =yield tDM/yr/ha
- * p=interest rate
- * NPV=net present value
- * I=income
- * B=break-even price
- * K=cost

$$1. NPV = \sum_{n=1}^{24} (I_n - K_n) \cdot (1.0p)^{-n}$$

$$\sum_{n=1}^{24} K_n \cdot 1.0p^{-n}$$

$$2. B (NPV=0) = \frac{\sum_{n=1}^{24} S_k n \cdot 1.0p^{-n}}{\sum_{n=1}^{24} K_n \cdot 1.0p^{-n}}$$

$$\sum_{n=1}^{24} S_k n \cdot 1.0p^{-n}$$

4. BASIC CALCULATION

4.1. Economics

Basic values are presented in Table 1 and 2. The interest rate of 6 % is generally used. Profit and risk is included in the interest. EF-harvest is stored for about 3 months after the harvest. The cost is handled as interest on storage in the calculation. No subsidies are included in the calculation.

Land rent cost is 500 SEK/year/ha, which corresponds to 11 SEK/MWh for produced EF-fuel.

The calculation includes the cost to transform the land back to agricultural crop production after Salix-plantation. The cost is estimated to 3000 SEK/ha. The following steps are included:

- * stump destruction
- * stump removal
- * plowing and
- * harrowing.

It is presumed that the EF-fuel is distributed through an organization (Swedish Farmers Association). The administrative cost for distribution is 8 % of the fuel price 503 SEK/tTS, which corresponds to ca. 44 SEK/tTS (10 SEK/MWh).

Table 2 Parameters for basic calculation.- Economy.

Interest	6.00 %	
Annuity	7.97 %	(24 years)
Storage	3	(months)
Cost	1.50 %	(interest for storage)
Subsidies	0	
Annual subsidies	0	
Land rent costs	500	SEK/year/ha
Termination of EF	3000	SEK/ha
Administration	44	SEK/tTS (8%)

4.2 FUEL

The energy content of EF fuel is dependent on the heating value (MJ/kgDM), moisture content (%) and density (kg/m³). The effective heating value for EF fuels is about 4.4 MWh/tDM. This value has been determined according to the following;

- * Wa = effective heating value MWh/tDM
- * Wk = calorimetric value (19.5 MJ/kg DM)
- * Fh = moisture content (%)

$$W_a = (W_k * (1 - \frac{F_h}{100}) + (-0.0244 * (F_h + 53.64 * (1 - \frac{F_h}{100})))) * \frac{1}{3.6} * \frac{100}{(100 - F_h)}$$

The values determined is shown in Table 3.

Table 3 Parameters for basic calculation.- Fuel.

Price	115	SEK/MWh (at power plant)
Wk	19.5	MJ/kg (calorimetric)
Fh	50	%
Density	150	kg/m3s dry
1 m3s	0.66	MWh (according to formula)
1 m3s	75	SEK
1 tDM	4.38	MWh (according to formula)
1 tDM	503	SEK

EF fuel can be compared to other woodfuels and the same price is used for EF fuel as for conventional wood chips. The price is 115 SEK/MWh, which is the average price according to the National Price and Competition Board and the National Board of Energy in 1988/89.

Table 4 shows prices of different import fuels, including energy and environmental taxes but excluding v.a.t (value added tax 25 %).

4.3 MACHINERY

The machinery used in EF is developed from existing agricultural and forestry machines. The technique is not yet fully developed and work to improve harvesters and weeding equipment is still going on.

A separate analysis of new harvesters is given in chapter 7.2.

Table 5 shows costs for fertilizing with a "shuttle". Shuttle fertilization is a new method to spread nutrients in closed stands

Table 4 Prices of different import fuels

	Energy content		Price/unit		Cost			
Oil	10.8	MWh/m ³	2000	SEK/m ³	185	SEK/MWh (at PP)		
Coal	7.6	MWh/ton	1170	SEK/ton	154	"	"	"
Gasol	12.8	MWh/ton	3500	"	"	274	"	"

of Salix. The equipment is towed by a mini tractor. This machine can also be used in other parts of agriculture or forestry. The actual spreader is made especially for shuttle fertilization.

The planting is done by a tractor towing a 2-row planter. Three people are required for the operation including the tractor driver. The tractor is a common agricultural tractor in the size 75-100 kWh.

Table 5 Shuttle fertilization. Economical life 4 years, interest rate 12 % and capacity 1.9 ha/hour.

Machine	Cap. Cost SEK	Use hr/yr	Cap. Cost SEK/hr	Use SEK/hr	Gas SEK/hr	Total SEK/hr
Tractor	40,500	400	33.3	5.0	25.0	63.3
Spreader	29,500	100	97.1	14.7	10.0	121.8

The harvester in the basic calculation is the "ESM" machine. The harvesting is calculated in the following steps:

- * harvesting
- * field transport and unloading (at field edge)
- * chipping

In the basic calculation is presumed that 50 % of the harvested volume is transported from the field in a separate operation, as the harvester can not take the whole volume in one

go. Technically, it is possible but practically the average will be very much decreased by the transport load. The field transport and the unloading is done with a modified forwarder commonly used in forestry.

The chipping is combined with harvesting using a harvester/chipper. Further transport of chipped material should be carried out by container. Ordinary bulk-trucks can be used, providing the volumes are big enough.

4.4 BIOLOGY

In the calculation it is presumed that production is equal throughout the growing period (24 years). However, for the first 3 years an adjustment has been made to lower yields. Harvest is made each 4th year.

The amount of fertilizer has been adjusted to growth. To achieve a yield increase with 1 tDM per year 5 kg nitrogen is needed. This corresponds to ca 20 kg N-P-K 20-5-9. The amount of fertilizers corresponds to the nitrogen that is stored in the stems, about 0.5 %, at harvesting time.

4.5 CULTIVATION/MANAGEMENT PROGRAMME

It is presumed that plantations are located on "good" agricultural land (i.e. land suitable for "conventional" crops) in southern and middle Sweden. These areas corresponds to GSS (southern Sweden) and SS (middle Sweden), a terminology commonly used for descriptions of agricultural areas in Sweden.

The same management programme is assumed for both areas. In GSS area ca 20 % higher yields are expected. The fertilizer amount is correspondingly higher in this area as well. The programme for cultivation/management is shown in Table 6.

5. COSTS

Establishment of EF is costly. The total establishment cost is about 10000 SEK per ha. The highest separate cost is the planting, ca 7800 SEK/ha, mainly due to the price of the cuttings, ca 0.30 SEK/cutting. In total 18000-20000 cuttings/ha are used.

The annual management cost is ca SEK 1500/ha incl land rent (which is SEK 500/yr/ha in the basic calculation).

The harvesting of EF includes the following operations:

- * harvest
- * field transport/unloading at field edge

Table 6 Expected production, yield and fertilization during one growing period.

Year	Harvest time	Prod factor	Prod tDM/yr	Yield tDM	NPK2059 kg/ha
1	0	0.30	4	0	0
2	0	0.60	7	0	300
3	0	0.90	11	0	300
4	1	1	12	34	300
5	0	1	12	0	300
6	0	1	12	0	300
7	0	1	12	0	300
8	1	1	12	48	300
9	0	1	12	0	300
10	0	1	12	0	300
11	0	1	12	0	300
12	1	1	12	48	300
13	0	1	12	0	300
14	0	1	12	0	300
15	0	1	12	0	300
16	1	1	12	48	300
17	0	1	12	0	300
18	0	1	12	0	300
19	0	1	12	0	300
20	1	1	12	48	300
21	0	1	12	0	300
22	0	1	12	0	300
23	0	1	12	0	300
24	1	1	12	48	300

- * storage
- * chipping
- * transport (container)
- * administration

The total cost for these steps is: 18000 SEK/ha

In Figure 1 the cost is distributed to different sectors.

6. RESULTS

The result for the basic calculation can be seen in Figures 2 and 3. The area is SS. Figure 2 illustrates the cash flow and net present value for the cultivation period.

According to the prerequisites for the basic calculation the cultivation is not profitable as the net value remains negative during the whole period.

Table 7 Management programme for EF on agricultural land. Area SS. Including costs per operation in SEK/ha.

Year	Operation	Cost SEK/ha	Income SEK/ha
1	Planning	180	
	Chemical weeding	1300	
	Transport (cuttings)	220	
	Planting (incl. cuttings)	7800	
	Tending	90	
	Land rent	500	
TOT		10090	
2,3,5,6	Shuttle fertilization	900	
7,9,10,11	Tending	90	
13,14,15	Land rent	500	
17,18,19			
21,22,23			
TOT		1490	
4,8	Shuttle fertilization	900	
12,16	Harvesting (ESM)	4160 (*)	
20,24	Fieldtransp, unloading	1580 (*)	
	Chipping	6700 (*)	
	Trp (container)	3450 (*)	
	Administration	2110 (*)	
	Storage	360 (*)	
	Selling		
24152 (*)			
	Tending	90	
	Land rent	500	
TOT		19800	
24152			
24	Close down of plantation	3000	
TOT		3000	

(*) In average during 24 years, at 12 tDM/yr/ha.

To achieve zero-result (net present value=0) the fuel price must raise to 138 SEK/MWh incl land rent and to 127 SEK/MWh excluding land rent (Figure 3).

In Figure 4 a comparison between EF-fuel and coal, oil and natural gas has been made. For the EF-fuel three different price levels are shown, one is the present price (115 SEK/MWh) and the

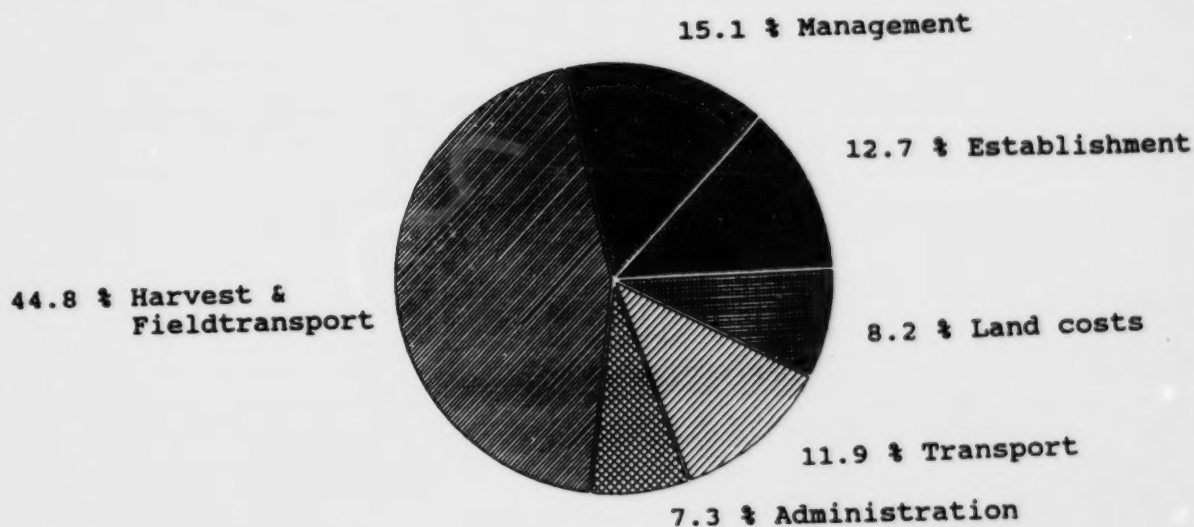


Figure 1 Production costs for EF-fuel

other two are the prices giving zero-result (including and excluding of land rent). It is shown that EF and other wood fuels are cheaper than fossil fuels mostly due to the new taxes on fossil fuels.

Energy forestry can be compared to conventional crops by defining a so called "crop rotation". With the help of agricultural statistics a hypothetic, though realistic crop rotation schedule is set up. The cost to grow the different crops in terms of machinery, land rent, etc is calculated and compared to that of EF. The most common way of comparing EF and crops is to use the regional calculations from agriculture. The profitability is expressed in different levels.

Level 1, called TB1 (Gross margin 1) = GM1 is defined as: income minus variable expenses but including maintenance (of buildings and machinery) and interest rates. Expenses are:

- * seed
- * fertilizers
- * herbicides and pesticides
- * oil, gas etc for tractors and machinery

The next level, TB2 (Gross margin 2) = GM2 is defined as: TB1 minus maintenance and interest rates, these are:

- * maintenance for tractors etc
- * " for special machinery

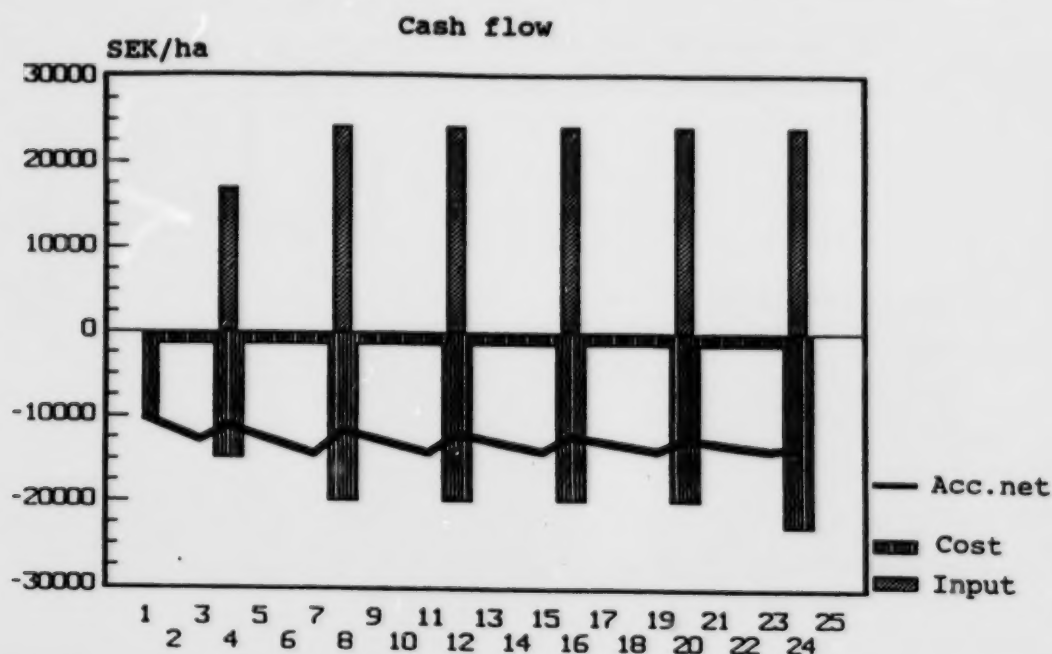


Figure 2 Cash flow and accumulated NPV

- * " for buildings
- * interest rate for storage
- * the total cost for labour (hired)

The third level, TB3 (Gross margin 3) = GM3 is defined as: TB2 minus the following:

- * depreciation and interest on private special machinery
- * depreciation and interest on buildings
- * personal labour

In order to compare EF and other crops GM3 must be adjusted to the combined cost for machinery and project management. GM3 can thereafter be used for comparison.

Table 8 shows a crop rotation schedule and the way the combined costs for the different crops have been calculated.

In Table 9 the defined crop rotation and EF is compared. It is shown that EF is not competitive with conventional crops today. The difference though is moderate.

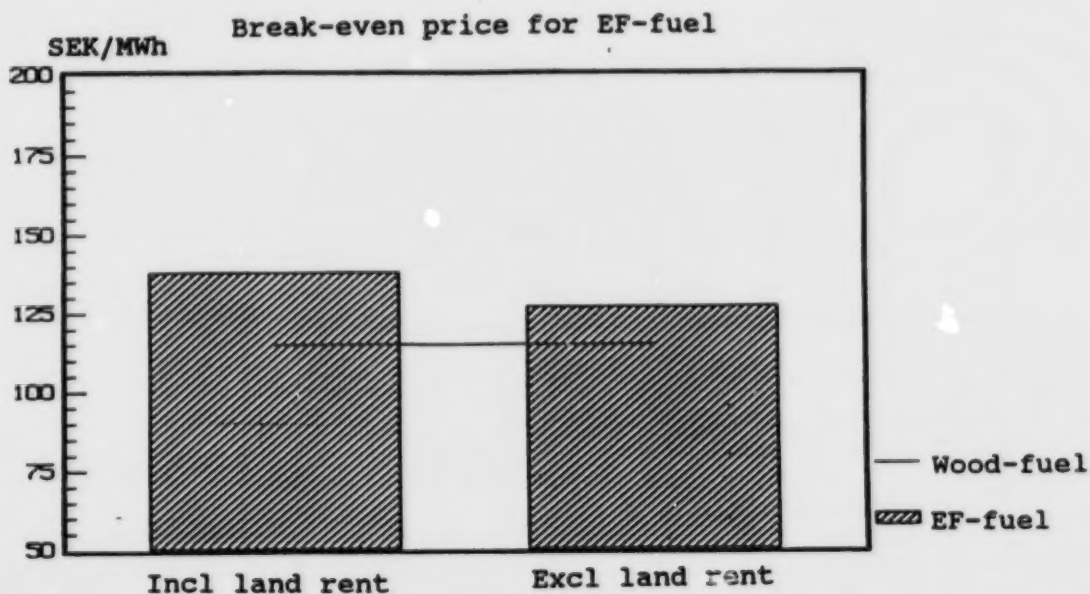


Figure 3 Break-even price for EF-fuel.

Table 9 Yield. EF compared to crop rotation. Area SS. Excluding land rent. GM3

	Yield		
	Low	High	
Crop rot.	-198	529	SEK/ha
EF	-557	-410	

7. SENSITIVITY ANALYSIS

7.1 Basic calculation

The sensitivity analysis studies shows how sensitive different factors are to changes. The analysis includes only those factors that are possible to influence in the future.

The sensitivity analysis is based on the basic calculation. The old ESM machine is used as harvester, though with a certain modification.

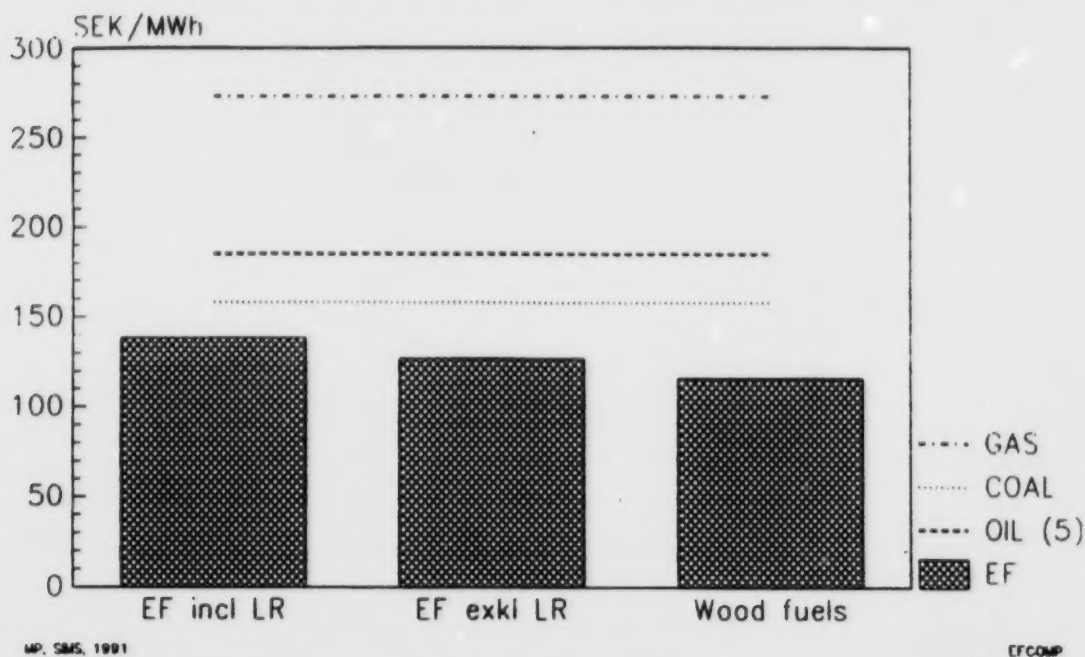


Figure 4 Comparison with other fuels.

The following costs and prerequisites varies:

- * yield
- * interest rate
- * land rent
- * harvesting cost
- * subsidies
- * planting cost
- * fuel quality

The results from these analyses are shown in Tables 10 and 11.

Harvesting, land rent and yield shows a large effect on the result. Interest rates and subsidies show moderate effects.

In Table 11 an analysis of certain cases have been made. The analyses shows that improved quality, for example drying the biomass, can give a good result.

The investment cost should be possible to lower in the future through cheaper cuttings and improved planting machinery. Also a

Table 8 Table 8. Crop rotation schedule. Area SS. Excluding land rent. L=low yield, H=high yield

Crop	Yield	Part %	GM3 SEK/ha	Combined cost SEK/ha	Result SEK/ha
Aut. wheat	L	9.8	1447	1442	5
	H		2214	1442	772
Aut. rye	L	0.8	480	1430	-950
	H		955	1430	-475
Spr. wheat	L	11.9	1987	1232	755
	H		2581	1232	1349
Barley	L	37.4	912	1232	-320
	H		1655	1232	423
Oats	L	30.8	795	1232	-437
	H		1534	1232	302
Aut rape	L	0.1	1733	1553	180
	H		2461	1553	908
Spr rape	L	5.8	1558	1518	40
	H		2818	1518	1295
Peas	L	3.5	130	970	-840

Table 10 Sensitivity analysis

Analyses	Variation	Effect SEK/MWh
Land rent	+/-500SEK/ha/yr	11
Harvesting	+/-10%	8
Yield	+/-2 tDM/ha/yr	3-8
Interest	+/-2%	5
Subsidies	+/-2500 SEK/ha	4

lower number of cuttings per ha should have a positive effect on the costs.

Table 11 Sensitivity analysis, special cases

Analyses	Change	Effect SEK/MWh
Moisture	+5%	4
Cuttings	+0.1 SEK/Cutt	3
Planting	+1 hr/ha	1

7.2 Future calculation

EF is still in an initial development stage, and it might be of interest to compare two different machinery scenarios in the form of calculations. There are two new concepts of machinery, both of them sponsored by the National Energy Board and the Swedish Farmers Association.

Table 12 New harvesters

Type	Production ha/work-period	Cost SEK/tDM
Harvester, chipper	0.9	106
Harvester	1.6	30

As these two machines have not yet been tested, one can only perform a theoretical comparison. These calculations can serve as a base for further discussions concerning the economy of EF. Both machines are expected to be running by 1991/92.

The technical development will have an impact on the costs in a couple of years from now (1989). The planting cost will probably decrease due to better planting machinery and cheaper cuttings. The transport and chipping of EF material will be more effective once commercially introduced.

In Table 13 the different EF machinery are presented. The operation costs are calculated for the present situation and in the future.

The results (Figure 5) is shown inclusive and exclusive of land rent (500 SEK/ha/year). New and more effective machinery has a strong influence on the costs. The production cost for EF fuel can be lowered to 85-90 SEK/MWh. This can be compared to today's price on woodfuel which is ca 115 SEK/MWh and with the price for coal, ca 154 SEK/MWh. In this scenario, it is not considered to

Table 13 Prerequisites for the future calculus

Machinery	Operation	Present		Future	
ESM:	Harvest	100	SEK/tDM	90	
SEK/tDM(-10%)					
	Planting	5	hr/ha	3	hr/ha
	Cuttings	0.30	SEK/cutt	0.20	SEK/cutt
	Chipping	40	SEK/tDM	126	
SEK/tDM(-10%)					
	Fieldtrp	33	SEK/tDM	30	
SEK/tDM(-10%)					
	Roadtrp	72	SEK/tDM	65	
SEK/tDM(-10%)					
Harvesting (new):	Harvest			30	SEK/tDM
	Planting	5	hr/ha	3	hr/ha
	Cuttings	0.30	SEK/cutt	0.20	SEK/cutt
	Chipping	140	SEK/tDM	126	
SEK/tDM(-10%)					
	Roadtrp	72	SEK/tDM	65	
SEK/tDM(-10%)					
Harvesting/chipp. (new):	Harvest/chipping			106	SEK/tDM
	Planting	5	hr/ha	3	hr/ha
	Cuttings	0.30	SEK/cutt	0.20	SEK/cutt
	Roadtrp	72	SEK/tDM	65	
SEK/tDM(-10%)					

improve the old ESM harvester.

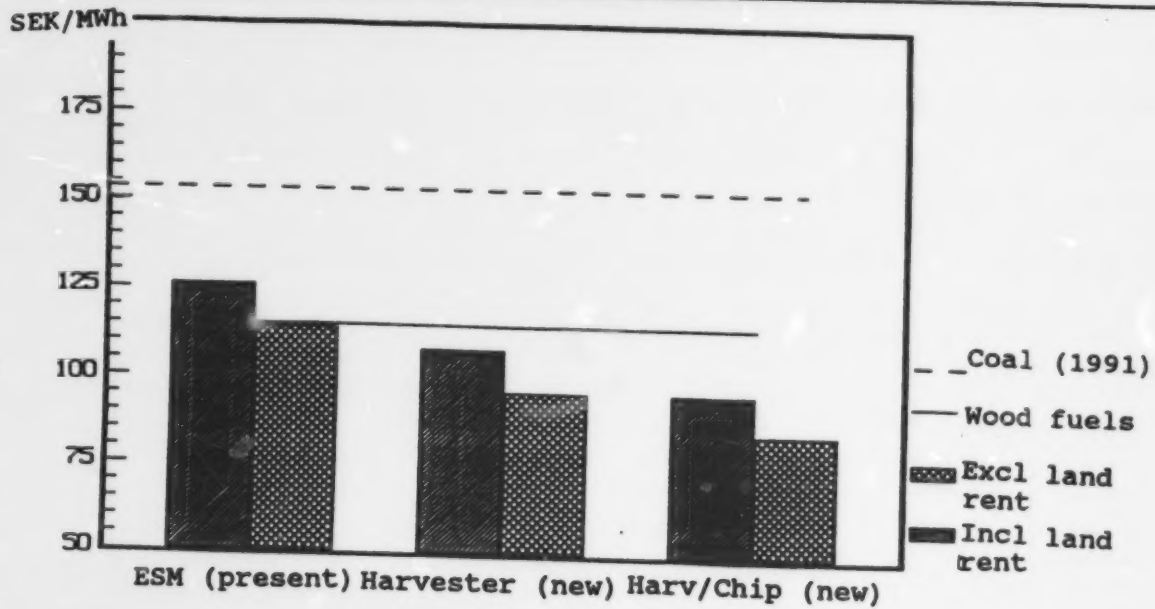


Figure 5 Future calculation. Break-even price on EF-fuel.

ENCLOSURE

OPERATION	Quantity	Unit	SEK/unit	SEK/ha
Planning	2	hr/ha	90	180 (labour)
TOTAL				180
Liming				
Tractor	0.50	hr/ha	110	55 (70hp, SLU 1989)
Spreader	0.50		30	15 (SLU 1989)
Labour	0.50		90	45 (salary driver)
TOTAL				115
Soil preparation				
Tractor	2.40	hr/ha	110	264 (70hp, SLU 1989)
Cultivato	2.40		65	156 (SLU 1989)
Labour	2.40		90	216 (salary driver)
TOTAL				636
Shuttle fert.				
Tractor	0.50	hr/ha	63	32 (Suzuki 4WD)
Spreader	0.50		122	61 (Vicon)
Labour	0.50		90	45 (salary driver)
TOTAL				138
Tractor fert.				
Tractor	0.50	hr/ha	110	55 (70hp, SLU 1989)
Spreader	0.50		50	25 (SLU 1989)
Labour	0.50		90	45 (salary driver)
TOTAL				125
Air fert. (entreprenade)				
Helicopter	3.05	SEK/kg	3.05	(incl. NPK 20-5-9)
Adding	160	SEK/ha	160	160 (moving)
Tractor	0.50	hr/ha	110	55 (SLU 1989)
Carrier	0.50		20	10 (SLU 1989)
Labour	0.50		90	45 (salary driver)
TOTAL				270

Spreader-fert. (entr.)

Tract+spreader	3.55	SEK/kg		3.55 (incl NPK)
Adding	160	SEK/ha		160 (moving)
Tractor	0.50	hr/ha	110	55 (SLU 1989)
Carrier	0.50		90	45 (salary driver)
TOTAL				270

Chem weeding

Tractor	1	hr/ha	110	110 (70hp, SLU 1989)
Spreader	1		60	60 (SLU 1989)
Labour	1		90	90 (salary driver)
Gardopr 500Fw	31		106	18 (SLU 1989)
Roundup	41		165	660 (SLU 1989)
TOTAL				240

Mech weeding

Tractor	1	hr/ha	110	110 (70hp, SLU 1989)
Tool	1		40	40 (SLU 1989)
Labour	1		90	90 (salary driver)
TOTAL				240

Transport

Tractor	1	hr/ha	110	110 (70hp, SLU 1989)
Carrier	1		20	20 (SLU 1989)
Labour	1		90	90 (salary driver)
TOTAL				220

Planting

Tractor	5	hr/ha	110	550 (100hp, SLU 1989)
Machinery	5		100	500 (Wilstrand)
Labour	5		90	450 (salary driver)
Labour (2persons)	5		90	900 (salary planters)
Cuttings	18000	cutt/ha	0.30	5400
TOTAL				7800

Tending

TOTAL	1		90	90 (labour)
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90

Harvesting

Harvest (ESM)				99 SEK/tDM *
Fieldtrp/unload.				33 SEK/tDM *
Chipping				140 SEK/tDM *
TOTAL				272

Roadtrp

Transport 1.				72 SEK/tDM *
TOTAL				72 (container)

Roadtrp	
Transport 2.	36 SEK/tDM *
TOTAL	36 (Bulktruck)

Administration (operation base)	
Adm	44 SEK/tDM
TOTAL	44

* Cost est. from: Official tables for Forest labour cost 88-06-16, sys 3.

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APPENDIX E

A report by Dr. C.P. Mitchell, U.K. sub-contractor.

SHORT ROTATION COPPICE IN THE UK

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INTRODUCTION

Short rotation energy coppice is an important source of renewable energy as it can be grown on those areas of agricultural land which are surplus to agricultural production. Hence it can be seen as an alternative farm crop, and as such, a possible solution to the problem of agricultural surpluses as well as providing a source of energy. Studies have indicated that up to one million hectares of land in the UK surplus to agricultural production may be suitable for growing energy coppice. However, its development as an agricultural crop will only happen if it can be produced at costs competitive with alternative fuels and there is a reliable and long term market offering good returns.

Currently in the UK the market, if any, is in its infancy and support for the crop in terms of subsidy is non-existent except for set-aside payments. These grants are administered through the European Community and entail setting aside 20% of the farm area from cereal production. They amount to £150/ha/yr for five years for short rotation coppice. Grants for establishing and maintenance of short rotation forestry on farms will be available from spring 1992 but the level and precise nature of those grants are unknown at this time.

THE POSITION OF ENERGY COPPICE IN THE UK

The role of energy coppice as a source of energy has been under investigation in the UK with Department of Energy and EEC funding since the late 1970s. Initial feasibility studies indicated the crop to be economically viable with sufficient land being potentially available, around 80,000 ha (early 1980 agricultural costs, prices and markets), to justify an experimental programme.

Initial screening and spacing trials established sufficient information to enable selection of poplars and willows grown at close spacing with cutting cycles of 3 to 5 years for use in a series of large scale production trials. The purpose of these trials was to establish "production scale" yields, costs and performance data on the

Loughry Coppice Harvester as well as providing a physical demonstration to potential growers.

Some ten years later we are in a better position to evaluate the growing and management of the crop although much R&D remains to be done. Poplars and willows are the front runners in terms of yield with poplars generally being favoured as the genetic base is better established, yields more reliable and they are not troubled by the leaf rust which is having a yield suppressing influence on some willow clones. If willows were to be bred specifically for biomass production and disease tolerance/resistance, then it would be possible to recommend them more strongly.

Establishment and management of a coppice plantation (whether for poplar or willow) involves a series of operations from site preparation through planting to harvest with herbicides and fertilizers applied when appropriate. The current recommendations are for poplars to be planted at a spacing of 1 x 1.5 m and grown on a 5 year cutting cycle; willows to be planted at 1 x 1 m spacing and grown on a 3 year cutting cycle. These are not hard and fast recommendations as the management system and species choice will vary with site. There is always the possibility to opt for longer cutting cycles, but this would necessitate wider spacings if losses due to inter-stool competition are to be avoided.

Once established, the crop is allowed to grow before harvest at the appropriate interval (cutting cycle). Availability of machinery for harvesting coppice is currently limited. In the UK the prototype Loughry Coppice Harvester has been developed and is currently undergoing evaluation in a series of trials harvesting poplars and willows. In Sweden there are two machines for relatively small-scale operation and one for larger scale operation. None of the Swedish machines seems to be significantly more cost effective than the Loughry Coppice Harvester. Analyses of the costs of growing and harvesting coppice crops (Mitchell & Ford-Robertson, 1990) have shown that harvesting, transpirational drying, chipping and transport can amount to 70% of the total delivered cost of wood fuel from coppice. These steps in the process are obviously critical to its economic success.

Whilst it might appear that the technology for growing the crop is fully established, this is not the case. Main areas for which reliable data are missing include: clone/site interaction; requirement for fertiliser addition of long term site productivity; application (rate and timing) of herbicides and effects on coppice growth; impacts of pests and diseases; ability to harvest the crop over a range of terrain types; reliable yield and cost data.

SHORT ROTATION COPPICE TRIALS

Trials have been established by the Wood Supply Research Group (WSRG) since 1986 (Mitchell *et al* 1989), to obtain information on costs, logistics, productivity and biology of short rotation coppice crops. Many different species and clones have been used in the screening trials, with new clones brought in from abroad for comparison as regards yields, disease susceptibility, growth habit and frost tolerance. Promising clones have been included in larger production trials, in which different cutting cycles and fertiliser regimes have been employed to assess their effect on yields and economics.

Table 1

UK COPPICE TRIAL SITES

Location	Species/clones (nos.)	Planting year	Area (ha)
Long Ashton Bristol England	Salix sp (2) Populus sp (11), Eucalyptus sp (2) & Alnus sp (1)	1986 1986-89	1.86 0.89
Swanbourne Buckinghamshire England	Populus sp (11)	1987	1.82
Castlearchdale Co. Fermanagh N. Ireland	Salix sp (9) Salix sp (5) Salix sp (5) & Populus sp (10)	1987 1988 1989	3.30 3.00 3.40
Kincardine Invernes-shire Scotland	Salix sp (18) Salix sp (6)	1987 1988-89	0.08 0.15
Guisachan Invernes-shire Scotland	Salix sp (13)	1988	0.72
Brahan Ross & Cromarty Scotland	Salix sp (10)	1989	0.96
Water Eaton Swindon England	Populus sp (106) Populus sp (5)	1989 1991	1.00 2.00
Markington Nth Yorks England	Populus sp (10)	1991	1.00

Buckfast Devon England	<i>Salix</i> sp (10)	1991	1.00
Parbold Lancs England	<i>Salix</i> sp (10)	1991	1.00

Since 1986, trials have been established at 11 sites across the UK (Figure 1), which vary in climatic and edaphic conditions. Initially the research was aimed at using marginal agricultural land, e.g. the surface water gleys of Fermanagh, Northern Ireland. However, site quality has improved over the period, as a result of land coming out of agriculture because of over production making better land available.

The production trials consist of willows and poplars, but one screening trial also has areas of Eucalyptus and alder (Table 1). The number of clones in the programme has increased each year, due largely to new material from Belgium (poplars) and Sweden (willows). This increase is a result of participation within the International Energy Agency Bioenergy Agreement Task V (Improvement of Energy-Dedicated Biomass Production Systems), partly to find higher yielding clones, but also to maintain a broad genetic base so as to avoid major problems with pests and diseases. In the last few years, leaf rust (*Melampsora epitea*) has become a major problem on some willow clones, causing severe reductions in biomass yield.

Mechanisation is vital to the production of biomass as an economic proposition, with harvesting being the primary concern. Development of a prototype machine is ongoing, in conjunction with the Loughry College in Northern Ireland, and field trials, harvesting 2, 3, and 4 year old willows and 3 year old poplars, have recently been completed in southern England and Northern Ireland.

YIELD

Yields obtained from *Salix viminalis* "Bowles Hybrid" at Long Ashton are shown in Table 2. A mean figure of the two 2 year old yields from 1989 and 1991 is given for productivity over the 4 year period, comparable with the yields for the blocks harvested on a 4 year cycle.

Table 2.

PRODUCTIVITY OF SALIX VIMINALIS "BOWLES HYBRID" AT LONG ASHTON

Block	Fertiliser	Productivity (dt/ha/yr)		
		1989	1991	Mean
5	No	5.65	8.25	6.98
6	Yes	7.10	9.49	8.35
7	Yes	-	7.82	7.82
8	No	-	7.31	7.31

Table 3

PRODUCTIVITY OF THREE YEAR OLD POPLARS AT SWANBOURNE (FEB 1991)

Clone	Productivity (dt/ha/yr)	
	Fertilised	Non-fertilised
Rap	10.26	9.69
Boelare	7.20	7.68
Beaupre	6.66	7.13
Dorschamp	6.21	6.47
Fritzi-Pauley	3.45	3.37
75.028/3	1.86	2.50

Table 4

ANNUAL HEIGHT GROWTH OF POPLARS AT SWANBOURNE
(m)

Clone	Year 1	Year 2	Year 3	Total
Rap	2.55	1.60	1.26	5.41
Boelare	1.69	1.64	1.14	4.47
Beaupre	1.98	1.39	1.21	4.58
Dorschamp	2.08	1.14	0.93	4.15
Fritzi-Pauley	2.13	1.21	0.88	4.21
75.028/3	1.81	1.31	0.94	4.06
Mean	2.04	1.38	1.06	4.48

These figures suggest that there is very little difference between the yields obtained by the different cutting cycles, at least in the early stages of growth. As a comparison, the 3 year old poplar harvested at Swanbourne also had similar yields to these (Table 3).

Table 2 also shows that for willows, although both fertilised blocks had slightly higher yields than the unfertilised, the difference is not as great as might have been expected; this was also the case with the poplars at Swanbourne (Table 3). It is possible that the effect of fertilisation has been masked as a result of the extremely dry summers

experienced in the south of England in the last 2 years, where water rather than nutrients has been the limiting factor. This lack of water is likely also to have reduced the crop yields, through reduced stomatal activity and hence decreasing photosynthetic capacity. Some indications of reduced growth can be seen from Table 4 which shows annual height growth of poplars over successive years at Swanbourne.

PESTS AND PATHOGENS

The major problem facing willow plantations is the leaf rust Melampsora epitea. In the trials laid down by the WSRG there is only one clone which has not shown any infection, while all the others show varying degrees of susceptibility. So far 7 pathotypes of this species have been identified. Two natural control agents have been identified: the first is a larva which feeds on the rust pustules, and the second is a hyperparasite (Darluca sp). The potential for these to be used as biological control agents has yet to be investigated. It would be impractical, environmentally undesirable and certainly uneconomic to have to use fungicides to prevent the spread of this disease, and trials in Northern Ireland have shown that the currently available chemicals are not totally effective (McCracken and Dawson 1991).

HARVESTING

There are a number of harvesting machines available for harvesting short rotation forest crops, designed for a range of tree sizes and ground conditions, but all of them are still in the development stage and are therefore not yet commercially available. Field trials have been carried out in the UK in the winter months 1990/91 with the Loughry Coppice Harvester.

The UK harvester is being developed at Loughry College in Northern Ireland. It is a semi-trailed single row harvester which cuts the stems with a circular saw, and collects the cut shoots upright in a chamber at the back. When the chamber is full, the forward motion of the machine stops, the shoots are compressed and the bundle is tied and ejected. It is envisaged that the bundles could be left, at the field edge, to air-dry over the summer months, during which time the moisture content of the wood could be reduced to about 30%. Equivalent storage times for chipped material resulted in a dry matter loss of 15- 20%. The bundles can then be picked up and fed directly into a chipper.

In January 1989 the Loughry Coppice Harvester (LCH) was used to harvest two blocks of the 2-year old Salix viminalis "Bowles Hybrid" at Long Ashton. This was the first large scale trial for the machine. Time-study was carried out on the machine and it was found to have a productivity of up to 3.31 wet tonnes per productive machine hour (wt/pmh), which equates to a cost of £18.79/dt; this compared very favourably with motor-manual harvesting using a brush-cutter, which had

a productivity of only 0.17 wt/pmh (Mitchell *et al* 1990). An experienced contractor using a chainsaw to harvest some 3 year old poplars at Swanbourne only reached a maximum productivity of 1.2 wt/pmh.

After harvesting, the cut stools were sprayed with contact and residual herbicides, and left to resprout. In February 1991, the LCH was used at Long Ashton to cut the 2-year old blocks for the second time, and also the 4-year old blocks. The results from this time study show that the productivity of the machine on the 2 year old willow has increased to 4.41 wt/pmh (£13.51/dt), but only 3.7 wt/pmh (£16.09/dt) was achieved with the 4 year old. The main reason for reduced productivity in the 4 year old stand was the height of the trees (7m); this meant that the centre of gravity was higher than that for which the packing chamber was designed and therefore smaller bundles had to be made. When the movement of the harvester was studied, it was found that in all crops less than half of the time taken to produce a bundle was spent cutting, with the remainder being taken up by packing, tying and ejecting. Productivity is therefore increased by producing fewer, bigger bundles as was the case in the 2 year old willows.

ECONOMICS

With the current level of interest in short rotation coppice crops, much more emphasis has been placed on the economics of production. With the limited information on yields and harvesting costs, it has been possible to produce economic models for a period of approximately 20 years.

The economics of coppice energy have been examined (Mitchell 1991) with respect to two simple models: a 3- and a 5-year cutting cycle, both using a yield of 12 dt/ha/yr. A harvesting cost of £18.79/dt has been assumed based on trials with the LCH in 1989 (Mitchell *et al* 1990). Two scenarios have been modelled: "Farmer" - farmer grows the crop using opportunity labour and contractors are used to harvest the crop; "Contractor" - contractors are used for all operations. Costs of operations for each scenario are shown in Table 5.

Table 5

COSTS OF OPERATIONS

Operation/cost/years in which it occurs

		Farmer	Contractor
<u>5 year cutting cycle</u>			
Site preparation	0	60	98
Planting	0	1005	1173
Herbicide 1	0	5	19
Herbicide 2	1, 6, 11, 16	60	88
Cut-back	0	0	200
Beat-up	0	0	40

Fertilise	6,11,16	14	28
Harvest	5,10, 15,20	1123	1123

3 year cutting cycle

Site preparation	0	60	98
Planting	0	1500	1740
Herbicide 1	0	5	19
Herbicide 2	1,4,7,10, 13,16,19	60	88
Cut-back	0	0	200
Beat-up	0	0	40
Fertilise	4,7,10, 13,16,19	14	28
Harvest	3,6,9,12 15,18,21	674	674

This analysis has made the assumption that the wood produced would have a value as fuel, i.e. it assumes a market. The model has been run using three possible values for a gigajoule (GJ) of energy (Mitchell 1991):

£1.80/GJ (£13.95/wt) - Current average value for wood as a substitute for coal in existing boilers.

£2.40/GJ (£18.60/wt) - Long-term future "average" price in industrial markets.

£3.30/GJ (£25.58/wt) - Highest price industrial market in the future and also current price in domestic firewood market.

These models have shown that the economic feasibility of energy coppice is very sensitive to energy price and productivity. The results of this are summarised in Table 6.

TABLE 6

ECONOMIC MODELLING OF ENERGY COPPICE

System	Farmer		Contractor	
	Cost £/dt	EAV £/ha	Cost £/dt	EAV £/ha
5 YEAR CYCLE				
12 dt/ha/yr				
Set aside @£1.80/GJ	22.20	52	26.08	8
Set aside @£2.40/GJ	22.20	151	26.08	106
Set aside @£3.30/GJ	22.20	299	26.08	256
Yield 16 dt/ha/yr				
Set aside @£2.40/GJ	21.16	198	24.14	158

3 YEAR CYCLE

12 dt/ha/yr

Set aside @£1.80/GJ	25.94	11	30.57	0
Set aside @£2.40/GJ	25.94	123	30.57	65
Set aside @£3.30/GJ	25.94	292	30.57	234

The applicability of grant aid to this form of forestry will improve the economics for a farmer enormously. However, whilst grants will be made available, the conditions and levels are not known at present.

In order for the idea of energy coppice to be attractive to farmers, it has to be shown to provide at least as good a return as other competing agricultural crops. The usual way to express the financial performance of agricultural enterprises is in terms of gross margins (GM), but this concept is only applicable to annual crops. When dealing with longer time periods, the equivalent annual value (EAV) can be used as a "proxy" for gross margin. It can be seen that under the present grant system the best scenario gives an EAV of £299/ha/yr. This compares with a winter wheat enterprise with a GM of around £475/ha and lowland beef £270/ha. However, agricultural gross margins are a function of subsidies. Subsidies under the Common Agricultural Policy of the EEC are likely to be reduced by around 30% as a consequence of the GATT Agreement.

The economics of energy coppice are sensitive to energy price and grant aid as shown above, but they can also be improved in other ways. Higher yields can be achieved through better clone-site matching and good management practices, or a breeding programme could produce faster growing clones with reduced sensitivity to pests and diseases. Costs of production could also be reduced, particularly by increasing mechanisation; the most important area is to reduce the costs of harvesting, chipping and transport, which can account for 70% of the delivered fuel costs (Mitchell and Ford-Robertson 1990).

DISCUSSION

There is still the need for a great deal of basic information about coppice crops in the UK and the rest of Europe, such as site-clone interactions, spacings, cutting cycles, fertiliser and irrigation regimes etc. This information is being accumulated from laboratory and field trials, and stored in a database, to form the basis of a Coppice Decision Support System which is currently being developed at the WSRG. Such a system is designed to help growers in all stages of crop production, from the choice of species/clones, to the establishment and management techniques, through to the likely costs and yields, with the possibility of exploring a number of opportunities before selecting the most suitable options. Once this system is completed, it will provide a valuable service to anyone contemplating growing energy coppice.

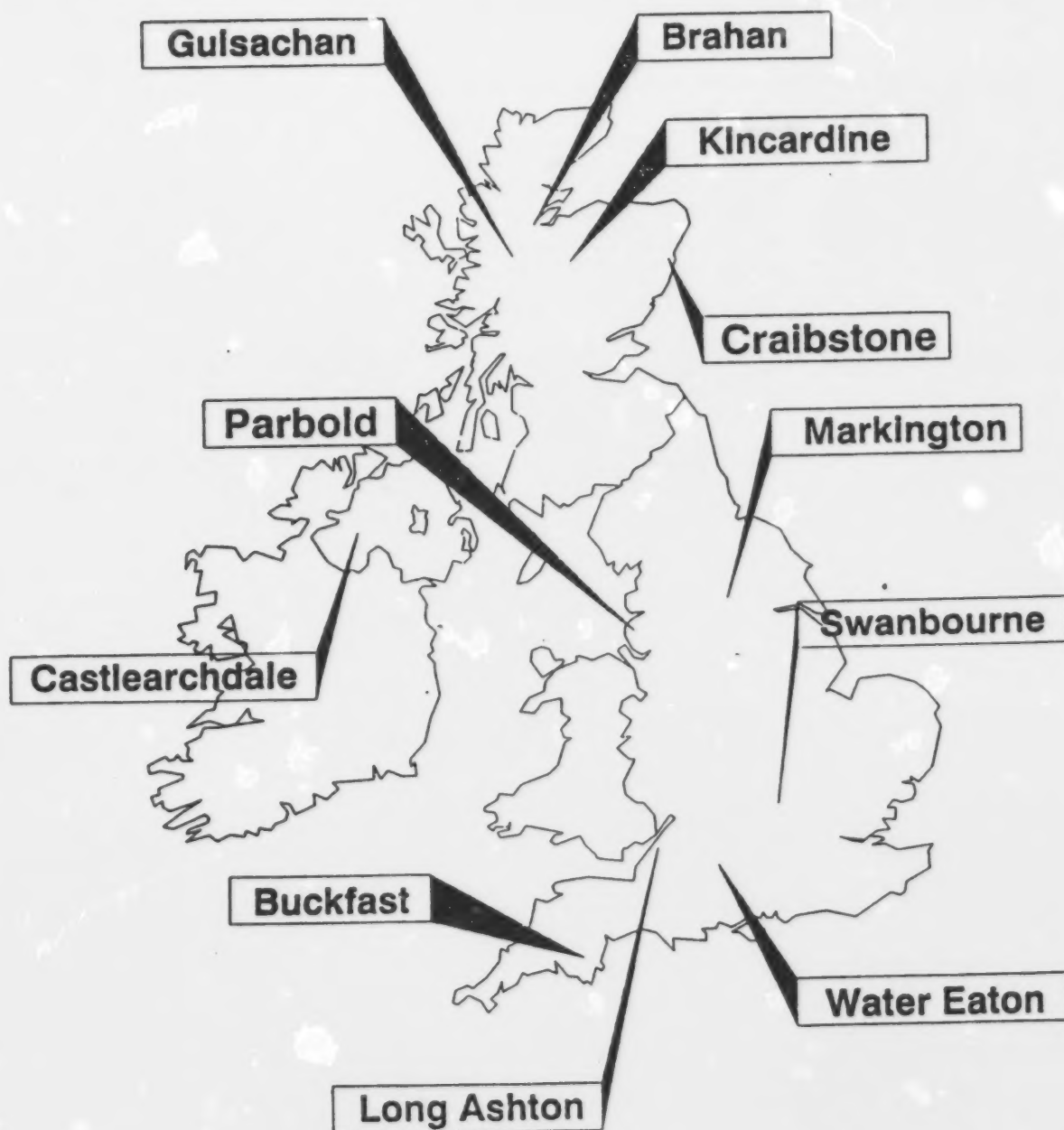
Yields can be increased, costs of production can be decreased and grants may be introduced, but it will all be to no avail unless reliable and

long term markets for wood fuel are established; and those are inextricably linked to fossil fuel prices. A fair price for energy must reflect the cost of replacing it, otherwise there is likely to be a heavy reliance on, and over-consumption of the resource. The EEC proposal for a carbon tax (which the UK government does not currently support) may provide the necessary impetus for making wood fuel increasingly attractive.

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Figure 1. UK Coppice Trial Sites.



APPENDIX F

Output from cash flow analysis for Canadian energy biomass scenarios.

Outputs include runs for:

From Table 11 in the text:

- High input costs @ 5,000 sph
- High input costs @ 10,000 sph
- High input costs @ 20,000 sph
- Low input costs @ 5,000 sph
- Low input costs @ 10,000 sph
- Low input costs @ 20,000 sph

From Table 12 in the text:

- Current input costs (contractor)
- Future input costs (farm labour)
- Subsidized input costs

Current input costs (farm labour)

Future input costs (contractor)

Figure 1 compares the effect of change of MAI on different input costs.

Table 1
ACTIVITYCASH FLOW BASED ON HIGH INPUT COSTS
VALUE 5000 sph

Life of Plantation	20 years		
Rotation length	6 years		
Number of Harvests	3		
Mean Annual Increment	12 Mg/ha/yr		
Total Yield/harvest	72.00 Mg/ha		
Total Yield for plantation	216.00 Mg/ha		
Value of Harvested Biomass	\$2,880.00 /ha		
Discounted Total Yield	112.23 Mg/ha		
Present Value of Costs	\$9,860.99	\$87.86 /odMg	
Present Value of Revenues	\$4,489.33	\$40.00 /odMg	
Net Present Value	(\$5,371.66)	(\$47.86) /odMg	
Annual Equivalent Cost	\$791.27		
Annual Equiv. Net Value	(\$431.04)		
Internal Rate of Return	ERR		
Benefit/Cost ratio	0.46		
Interest Rate	0.05		
Density	5,000 stem per ha		
Mean Annual Increment	12.00 odMg/ha/yr		
Biomass value	\$40.00 \$/odMg		
Distance to mill	40 km		
Land costs	\$150.00 /ha/yr		
Total Herbicide	\$85.00 /ha		
Ploughing	\$80.00 /ha		
Disking	\$80.00 /ha		
cultivate	\$25.00 /ha		
Site Preparation	\$270.00 /ha	Cost for	
Planting	\$1,375.00 /ha	cuttings planting	
Cut Back	\$500.00 /ha	225.00	50.00
Fertilize	\$200.00 /ha/application		
Weed Control	\$40.00 /ha/application		
Harvest Biomass	\$1,000.00 /ha/harv.	13.89 /odMg	
chipping	\$1,080.00 /ha	15.00 /odMg	
Transport to mill	\$720.00 /ha	0.25 /odMg/km	

TABLE 2. CASH FLOW BASED ON HIGH INPUT COSTS

=====										
Rotation: Density		6 years			MAI: 12		NPV: *****			
REVENUE		COSTS								
Year or a	+SELL	+LAND	+SITE	+PLAN	+WEED	+FERT	+CUT	+HARV	+CHIP	+TRAN
=====										
0	0	150	270	1375	0	0	0	0	0	0
1	0	150	0	0	40	0	500	0	0	0
2	0	150	0	0	40	0	0	0	0	0
3	0	150	0	0	40	0	0	0	0	0
4	0	150	0	0	0	200	0	0	0	0
5	0	150	0	0	0	200	0	0	0	0
6	0	150	0	0	0	200	0	0	0	0
7	0	150	0	0	40	0	0	1000	0	0
8	2880	150	0	0	40	0	0	0	1080	720
9	0	150	0	0	40	0	0	0	0	0
10	0	150	0	0	0	200	0	0	0	0
11	0	150	0	0	0	200	0	0	0	0
12	0	150	0	0	0	200	0	0	0	0
13	0	150	0	0	40	0	0	1000	0	0
14	2880	150	0	0	40	0	0	0	1080	720
15	0	150	0	0	40	0	0	0	0	0
16	0	150	0	0	0	200	0	0	0	0
17	0	150	0	0	0	200	0	0	0	0
18	0	150	0	0	0	200	0	0	0	0
19	0	150	0	0	0	0	0	1000	0	0
20	2880	0	0	0	0	0	0	0	1080	720
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
=====										
NPV	4,489.33	1963	270	1375	251	1084	476	1637	1684	1122
% of		20%	3%	14%	3%	11%	5%	17%	17%	11%

TABLE 3 CASH FLOW BASED ON HIGH INPUT COSTS

Rotation:	6 years	MAI:	12
Density:	5000	NPV:	(\$5,372)

		Product Value			Break-even
		\$20	\$40	\$60	Value
MAI -->	5	-7288.98	-6353.70	-5418.420	\$175.87
	10	-7522.80	-5652.24	-3781.683	\$100.43
	20	-7990.44	-4249.32	-508.2106	\$62.72
Break-even		-150.90	50.30	21.60	

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	-701.46	2104.38	4910.21
mean	11.67	-7600.74	-5418.42	-3236.11
slope		-46.76	140.29	327.35
y-int		-7055.16	-7055.16	-7055.16

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1870.56	-6353.70	46.76	-8224.25
	10	3741.11	-5652.24	93.53	-9393.35
	20	7482.22	-4249.32	187.06	-11731.55

TABLE 4. CASH FLOW BASED ON HIGH INPUT COSTS

=====					
Rotation:	6 years	MAI:	12		
Density	5000	NPV:	(\$5,372)		
Yr.	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
=====					
0	ERR	0.00	1,795.00	(1,795.00)	(1,645.00)
1	-1.38	0.00	2,452.14	(2,452.14)	(2,159.29)
2	ERR	0.00	2,624.48	(2,624.48)	(2,195.57)
3	-1.55	0.00	2,788.61	(2,788.61)	(2,230.12)
4	ERR	0.00	3,076.55	(3,076.55)	(2,394.66)
5	-1.70	0.00	3,350.79	(3,350.79)	(2,551.37)
6	ERR	0.00	3,611.96	(3,611.96)	(2,700.61)
7	ERR	0.00	4,457.67	(4,457.67)	(3,439.72)
8	-0.45	1,949.30	5,804.58	(3,855.29)	(2,735.80)
9	ERR	1,949.30	5,927.06	(3,977.76)	(2,761.59)
10	ERR	1,949.30	6,141.93	(4,192.63)	(2,884.37)
11	-2.06	1,949.30	6,346.57	(4,397.27)	(3,001.31)
12	-1.62	1,949.30	6,541.46	(4,592.16)	(3,112.68)
13	ERR	1,949.30	7,172.54	(5,223.25)	(3,664.21)
14	-0.44	3,403.89	8,177.63	(4,773.73)	(3,138.94)
15	ERR	3,403.89	8,269.02	(4,865.13)	(3,158.18)
16	ERR	3,403.89	8,429.36	(5,025.47)	(3,249.80)
17	ERR	3,403.89	8,582.06	(5,178.17)	(3,337.06)
18	-1.61	3,403.89	8,727.50	(5,323.60)	(3,420.17)
19	ERR	3,403.89	9,182.59	(5,778.70)	(3,815.90)
20	-0.35	4,489.33	9,860.99	(5,371.66)	(3,408.86)
21	ERR	4,489.33	9,860.99	(5,371.66)	(3,408.86)
22	ERR	4,489.33	9,860.99	(5,371.66)	(3,408.86)
23	ERR	4,489.33	9,860.99	(5,371.66)	(3,408.86)
24	ERR	4,489.33	9,860.99	(5,371.66)	(3,408.86)
25	ERR	4,489.33	9,860.99	(5,371.66)	(3,408.86)
26	ERR	4,489.33	9,860.99	(5,371.66)	(3,408.86)
27	ERR	4,489.33	9,860.99	(5,371.66)	(3,408.86)
28	ERR	4,489.33	9,860.99	(5,371.66)	(3,408.86)
29	ERR	4,489.33	9,860.99	(5,371.66)	(3,408.86)

Table 1
ACTIVITY

CASH FLOW BASED ON HIGH INPUT COSTS
VALUE 10000 sph

Life of Plantation	17 years	
Rotation length	5 years	
Number of Harvests	3	
Mean Annual Increment	12 Mg/ha/yr	
Total Yield/harvest	60.00 Mg/ha	
Total Yield for plantation	180.00 Mg/ha	
Value of Harvested Biomass	\$2,400.00 /ha	
Discounted Total Yield	102.23 Mg/ha	
Present Value of Costs	\$10,603.57	\$103.72 /odMg
Present Value of Revenues	\$4,089.16	\$40.00 /odMg
Net Present Value	(\$6,514.42)	(\$63.72)/odMg
Annual Equivalent Cost	\$940.53	
Annual Equiv. Net Value	(\$577.82)	
Internal Rate of Return	ERR	
Benefit/Cost ratio	0.39	
Interest Rate	0.05	
Density	10,000 stem per ha	
Mean Annual Increment	12.00 odMg/ha/yr	
Biomass value	\$40.00 \$/odMg	
Distance to mill	40 km	
Land costs	\$150.00 /ha/yr	
Total Herbicide	\$85.00 /ha	
Ploughing	\$80.00 /ha	
Disking	\$80.00 /ha	
cultivate	\$25.00 /ha	
Site Preparation	\$270.00 /ha	
Planting	\$2,750.00 /ha	Cost for cuttings planting
Cut Back	\$500.00 /ha	225.00 50.00
Fertilize	\$200.00 /ha/application	
Weed Control	\$40.00 /ha/application	
Harvest Biomass	\$1,000.00 /ha/harv.	16.67 /odMg
chipping	\$900.00 /ha	15.00 /odMg
Transport to mill	\$600.00 /ha	0.25 /odMg/km

TABLE 2. CASH FLOW BASED ON HIGH INPUT COSTS

Rotation: 5 years		MAI: 12								
Density 10000		NPV: *****								
REVENUE		COSTS								
Year or a	+SELL	+LAND	+SITE	+PLAN	+WEED	+FERT	+CUT	+HARV	+CHIP	+TRAN
0	0	150	270	2750	0	0	0	0	0	0
1	0	150	0	0	40	0	500	0	0	0
2	0	150	0	0	40	0	0	0	0	0
3	0	150	0	0	0	200	0	0	0	0
4	0	150	0	0	0	200	0	0	0	0
5	0	150	0	0	0	0	0	0	0	0
6	0	150	0	0	40	0	0	1000	0	0
7	2400	150	0	0	40	0	0	0	900	600
8	0	150	0	0	0	200	0	0	0	0
9	0	150	0	0	0	200	0	0	0	0
10	0	150	0	0	0	0	0	0	0	0
11	0	150	0	0	40	0	0	1000	0	0
12	2400	150	0	0	40	0	0	0	900	600
13	0	150	0	0	0	200	0	0	0	0
14	0	150	0	0	0	200	0	0	0	0
15	0	150	0	0	0	0	0	0	0	0
16	0	150	0	0	0	0	0	1000	0	0
17	2400	0	0	0	0	0	0	0	900	600
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
NPV	4,089.16	1776	270	2750	178	809	476	1789	1533	1022
% of		17%	3%	26%	2%	8%	4%	17%	14%	10%

TABLE 3 CASH FLOW BASED ON HIGH INPUT COSTS

Rotation:	5 years	MAI:	12
Density:	10000	NPV:	(\$6,514)

		Product Value			Break-even
		\$20	\$40	\$60	Value
MAI -->	5	-8260.83	-7408.92	-6557.012	\$213.94
	10	-8473.80	-6769.99	-5066.173	\$119.47
	20	-8899.76	-5492.13	-2084.496	\$72.23
Break-even		-188.90	63.00	27.00	

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	-638.93	1916.79	4472.52
mean	11.67	-8544.80	-6557.01	-4569.23
slope		-42.60	127.79	298.17
y-int		-8047.85	-8047.85	-8047.85

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1703.82	-7408.92	42.60	-9112.74
	10	3407.63	-6769.99	85.19	-10177.62
	20	6815.26	-5492.13	170.38	-12307.39

TABLE 4. CASH FLOW BASED ON HIGH INPUT COSTS

Rotation:		5 years		MAI:	
Density		10000		NPV:	
				12	
				(\$6,514)	
Yr.	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
0	ERR	0.00	3,170.00	(3,170.00)	(3,020.00)
1	-1.22	0.00	3,827.14	(3,827.14)	(3,534.29)
2	ERR	0.00	3,999.48	(3,999.48)	(3,570.57)
3	-1.52	0.00	4,301.82	(4,301.82)	(3,743.33)
4	ERR	0.00	4,589.77	(4,589.77)	(3,907.87)
5	-1.48	0.00	4,707.30	(4,707.30)	(3,907.87)
6	ERR	0.00	5,595.29	(5,595.29)	(4,683.94)
7	-0.51	1,705.64	6,796.34	(5,090.71)	(4,072.75)
8	ERR	1,705.64	7,033.24	(5,327.60)	(4,208.12)
9	-1.41	1,705.64	7,258.85	(5,553.22)	(4,337.04)
10	ERR	1,705.64	7,350.94	(5,645.30)	(4,337.04)
11	ERR	1,705.64	8,046.71	(6,341.07)	(4,945.11)
12	-0.49	3,042.04	8,987.76	(5,945.72)	(4,466.23)
13	ERR	3,042.04	9,173.37	(6,131.33)	(4,572.29)
14	ERR	3,042.04	9,350.15	(6,308.10)	(4,673.31)
15	ERR	3,042.04	9,422.30	(6,380.26)	(4,673.31)
16	ERR	3,042.04	9,949.13	(6,907.08)	(5,131.42)
17	-0.39	4,089.16	10,603.57	(6,514.42)	(4,738.75)
18	-0.39	4,089.16	10,603.57	(6,514.42)	(4,738.75)
19	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)
20	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)
21	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)
22	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)
23	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)
24	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)
25	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)
26	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)
27	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)
28	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)
29	ERR	4,089.16	10,603.57	(6,514.42)	(4,738.75)

Table 1
ACTIVITY

CASH FLOW BASED ON HIGH INPUT COSTS
VALUE 20000 sph

Life of Plantation	18 years		
Rotation length	4 years		
Number of Harvests	4		
Mean Annual Increment	12 Mg/ha/yr		
Total Yield/harvest	48.00 Mg/ha		
Total Yield for plantation	192.00 Mg/ha		
Value of Harvested Biomass	\$1,920.00 /ha		
Discounted Total Yield	109.47 Mg/ha		
Present Value of Costs	\$14,477.18	\$132.24 /odMg	
Present Value of Revenues	\$4,378.98	\$40.00 /odMg	
Net Present Value	(\$10,098.20)	(\$92.24)/odMg	
Annual Equivalent Cost	\$1,238.47		
Annual Equiv. Net Value	(\$863.86)		
Internal Rate of Return	ERR		
Benefit/Cost ratio	0.30		
Interest Rate	0.05		
Density	20,000 stem per ha		
Mean Annual Increment	12.00 odMg/ha/yr		
Biomass value	\$40.00 \$/odMg		
Distance to mill	40 km		
Land costs	\$150.00 /ha/yr		
Total Herbicide	\$85.00 /ha		
Ploughing	\$80.00 /ha		
Disking	\$80.00 /ha		
cultivate	\$25.00 /ha		
Site Preparation	\$270.00 /ha	Cost for	
Planting	\$5,500.00 /ha	cuttings planting	
Cut Back	\$500.00 /ha	225.00	50.00
Fertilize	\$200.00 /ha/application		
Weed Control	\$40.00 /ha/application		
Harvest Biomass	\$1,000.00 /ha/harv.	20.83 /odMg	
chipping	\$720.00 /ha	15.00 /odMg	
Transport to mill	\$480.00 /ha	0.25 /odMg/km	

TABLE 2. CASH FLOW BASED ON HIGH INPUT COSTS

=====										
Rotation: 4 years		MAI: 12								
Density 20000		NPV: *****								
REVENUE		COSTS								
Year or a	+SELL	+LAND	+SITE	+PLAN	+WEED	+FERT	+CUT	+HARV	+CHIP	+TRAN
=====										
0	0	150	270	5500	0	0	0	0	0	0
1	0	150	0	0	40	0	500	0	0	0
2	0	150	0	0	40	0	0	0	0	0
3	0	150	0	0	0	200	0	0	0	0
4	0	150	0	0	0	200	0	0	0	0
5	0	150	0	0	40	0	0	1000	0	0
6	1920	150	0	0	40	0	0	0	720	480
7	0	150	0	0	0	200	0	0	0	0
8	0	150	0	0	0	200	0	0	0	0
9	0	150	0	0	40	0	0	1000	0	0
10	1920	150	0	0	40	0	0	0	720	480
11	0	150	0	0	0	200	0	0	0	0
12	0	150	0	0	0	200	0	0	0	0
13	0	150	0	0	40	0	0	1000	0	0
14	1920	150	0	0	40	0	0	0	720	480
15	0	150	0	0	0	200	0	0	0	0
16	0	150	0	0	0	200	0	0	0	0
17	0	150	0	0	0	0	0	1000	0	0
18	1920	0	0	0	0	0	0	0	720	480
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
=====										
NPV	4,378.98	1841	270	5500	227	1031	476	2395	1642	1095
% of		13%	2%	38%	2%	7%	3%	17%	11%	8%

TABLE 3 CASH FLOW BASED ON HIGH INPUT COSTS

Rotation:	4 years	MAI:	12
Density:	20000	NPV:	(\$10,098)

		Product Value			Break-even
		\$20	\$40	\$60	Value
MAI -->	+NPV 5	-11968.39	-11056.10	-10143.81	\$282.38
	10	-12196.46	-10371.89	-8547.313	\$153.69
	20	-12652.60	-9003.46	-5354.308	\$89.35
Break-even		-257.40	85.80	36.80	

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	-684.22	2052.65	4789.51
mean	11.67	-12272.48	-10143.82	-8015.15
slope		-45.61	136.84	319.30
y-int		-11740.32	-11740.32	-11740.32

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1824.57	-11056.10	45.61	-12880.68
	10	3649.15	-10371.89	91.23	-14021.03
	20	7298.30	-9003.46	182.46	-16301.75

TABLE 4. CASH FLOW BASED ON HIGH INPUT COSTS

Rotation:		4 years		MAI:	
Density		20000		NPV:	
				12	
				(\$10,098)	
Yr.	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
0	ERR	0.00	5,920.00	(5,920.00)	(5,770.00)
1	-1.12	0.00	6,577.14	(6,577.14)	(6,284.29)
2	ERR	0.00	6,749.48	(6,749.48)	(6,320.57)
3	-1.40	0.00	7,051.82	(7,051.82)	(6,493.33)
4	ERR	0.00	7,339.77	(7,339.77)	(6,657.87)
5	-1.73	0.00	8,272.16	(8,272.16)	(7,472.74)
6	-0.63	1,432.73	9,309.40	(7,876.67)	(6,965.32)
7	ERR	1,432.73	9,558.14	(8,125.41)	(7,107.45)
8	-1.45	1,432.73	9,795.04	(8,362.30)	(7,242.82)
9	-1.91	1,432.73	10,562.12	(9,129.39)	(7,913.21)
10	-0.62	2,611.45	11,415.46	(8,804.01)	(7,495.75)
11	ERR	2,611.45	11,620.10	(9,008.65)	(7,612.69)
12	-1.43	2,611.45	11,814.99	(9,203.54)	(7,724.06)
13	ERR	2,611.45	12,446.07	(9,834.63)	(8,275.59)
14	-0.62	3,581.18	13,148.12	(9,566.94)	(7,932.14)
15	ERR	3,581.18	13,316.47	(9,735.30)	(8,028.35)
16	ERR	3,581.18	13,476.81	(9,895.63)	(8,119.97)
17	ERR	3,581.18	13,978.55	(10,397.38)	(8,556.27)
18	-0.50	4,378.98	14,477.18	(10,098.20)	(8,257.09)
19	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)
20	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)
21	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)
22	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)
23	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)
24	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)
25	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)
26	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)
27	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)
28	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)
29	ERR	4,378.98	14,477.18	(10,098.20)	(8,257.09)

TABLE 1
 CASH FLOW BASED ON LOW INPUT COSTS
 5000 SPH

ACTIVITY	VALUE	
Life of Plantation	20 years	
Rotation length	6 years	
Number of Harvests	3	
Mean Annual Increment	12 Mg/ha/yr	
Total Yield/harvest	72.00 Mg/ha	
Total Yield for plantation	216.00 Mg/ha	
Value of Harvested Biomass	\$2,880.00 /ha	
Discounted Total Yield	112.23 Mg/ha	
Present Value of Costs	\$3,523.76	\$31.40 /odMg
Present Value of Revenues	\$4,489.33	\$40.00 /odMg
Net Present Value	\$965.57	\$8.60 /odMg
Annual Equivalent Cost	\$282.76	
Annual Equiv. Net Value	\$77.48	
Internal Rate of Return	11.21%	
Benefit/Cost ratio	1.27	
Interest Rate	0.05	
Density	5,000 stem per ha	
Mean Annual Increment	12.00 odMg/ha/yr	
Biomass value	\$40.00 \$/odMg	
Distance to mill	40 km	
Land costs	\$50.00 /ha/yr	
Total Herbicide	\$65.00 /ha	
Ploughing	\$20.00 /ha	
Disking	\$20.00 /ha	
cultivate	\$10.00 /ha	
Site Preparation	\$115.00 /ha	Cost for
Planting	\$200.00 /ha	cuttings planting
Cut Back	\$250.00 /ha	25.00 15.00
Fertilize	\$100.00 /ha/application	
Weed Control	\$30.00 /ha/application	
Harvest Biomass	\$215.00 /ha/harv.	2.99 /odMg
chipping	\$360.00 /ha	5.00 /odMg
Transport to mill	\$432.00 /ha	0.15 /odMg/km

TABLE 2. CASH FLOW BASED ON LOW INPUT COSTS

=====										
Rotation:		6 years		MAI: 12						
Density:		5000		NPV: \$966						
REVENUE				COSTS						
Year or a	+SELL	+LAND	+SITE	+PLAN	+WEED	+FERT	+CUT	+HARV	+CHIP	+TRAN
=====										
0	0	50	115	200	0	0	0	0	0	0
1	0	50	0	0	30	0	250	0	0	0
2	0	50	0	0	30	0	0	0	0	0
3	0	50	0	0	30	0	0	0	0	0
4	0	50	0	0	0	100	0	0	0	0
5	0	50	0	0	0	100	0	0	0	0
6	0	50	0	0	0	100	0	0	0	0
7	0	50	0	0	30	0	0	215	0	0
8	2880	50	0	0	30	0	0	0	360	432
9	0	50	0	0	30	0	0	0	0	0
10	0	50	0	0	0	100	0	0	0	0
11	0	50	0	0	0	100	0	0	0	0
12	0	50	0	0	0	100	0	0	0	0
13	0	50	0	0	30	0	0	215	0	0
14	2880	50	0	0	30	0	0	0	360	432
15	0	50	0	0	30	0	0	0	0	0
16	0	50	0	0	0	100	0	0	0	0
17	0	50	0	0	0	100	0	0	0	0
18	0	50	0	0	0	100	0	0	0	0
19	0	50	0	0	0	0	0	215	0	0
20	2880	0	0	0	0	0	0	0	360	432
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
=====										
NPV	4,489.33	654	115	200	188	542	238	352	561	673
% of		19%	3%	6%	5%	15%	7%	10%	16%	19%

TABLE 3 CASH FLOW BASED ON LOW INPUT COSTS

Rotation:	6 years	MAI:	12
Density:	5000	NPV:	\$966

		Product Value			Break-even
		\$20	\$40	\$60	Value
MAI -->	5	-1868.32	-933.04	2.2378272	\$59.95
	10	-1447.44	423.11	2293.6691	\$35.48
	20	-605.69	3135.42	6876.5317	\$23.24
Break-even		27.20	8.40	5.00	

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	1262.63	4068.46	6874.29
mean	11.67	-1307.15	875.16	3057.48
slope		84.18	271.23	458.29
y-int		-2289.19	-2289.19	-2289.19

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1870.56	-933.04	46.76	-2803.60
	10	3741.11	423.11	93.53	-3318.00
	20	7482.22	3135.42	187.06	-4346.81

TABLE 4. CASH FLOW BASED ON LOW INPUT COSTS

=====					
Rotation:		6 years		MAI:	12
Density:		5000		NPV:	\$966
=====					
Year	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
=====					
0	ERR	0.00	365.00	(365.00)	(315.00)
1	-1.90	0.00	679.29	(679.29)	(581.67)
2	ERR	0.00	751.85	(751.85)	(608.88)
3	-1.92	0.00	820.96	(820.96)	(634.79)
4	ERR	0.00	944.36	(944.36)	(717.06)
5	-1.95	0.00	1,061.89	(1,061.89)	(795.42)
6	ERR	0.00	1,173.82	(1,173.82)	(870.04)
7	-2.09	0.00	1,383.47	(1,383.47)	(1,044.15)
8	0.05	1,949.30	1,973.68	(24.38)	348.78
9	0.04	1,949.30	2,025.25	(75.95)	329.44
10	0.02	1,949.30	2,117.33	(168.03)	268.05
11	0.00	1,949.30	2,205.03	(255.74)	209.58
12	-0.02	1,949.30	2,288.56	(339.26)	153.90
13	ERR	1,949.30	2,445.00	(495.71)	23.97
14	0.10	3,403.89	2,885.42	518.47	1,063.40
15	0.09	3,403.89	2,923.91	479.99	1,048.97
16	0.09	3,403.89	2,992.62	411.27	1,003.16
17	0.08	3,403.89	3,058.07	345.83	959.53
18	0.08	3,403.89	3,120.39	283.50	917.98
19	0.07	3,403.89	3,225.26	178.63	832.90
20	0.11	4,489.33	3,523.76	965.57	1,619.84
21	0.11	4,489.33	3,523.76	965.57	1,619.84
22	0.11	4,489.33	3,523.76	965.57	1,619.84
23	0.11	4,489.33	3,523.76	965.57	1,619.84
24	0.11	4,489.33	3,523.76	965.57	1,619.84
25	0.11	4,489.33	3,523.76	965.57	1,619.84
26	0.11	4,489.33	3,523.76	965.57	1,619.84
27	0.11	4,489.33	3,523.76	965.57	1,619.84
28	0.11	4,489.33	3,523.76	965.57	1,619.84
29	0.11	4,489.33	3,523.76	965.57	1,619.84

TABLE 1

CASH FLOW BASED ON LOW INPUT COSTS
10000 SPH

ACTIVITY	VALUE		
Life of Plantation	17 years		
Rotation length	5 years		
Number of Harvests	3		
Mean Annual Increment	12 Mg/ha/yr		
Total Yield/harvest	60.00 Mg/ha		
Total Yield for plantation	180.00 Mg/ha		
Value of Harvested Biomass	\$2,400.00 /ha		
Discounted Total Yield	102.23 Mg/ha		
Present Value of Costs	\$3,392.21	\$33.18 /odMg	
Present Value of Revenues	\$4,089.16	\$40.00 /odMg	
Net Present Value	\$696.95	\$6.82 /odMg	
Annual Equivalent Cost	\$300.89		
Annual Equiv. Net Value	\$61.82		
Internal Rate of Return	9.73%		
Benefit/Cost ratio	1.21		
Interest Rate	0.05		
Density	10,000 stem per ha		
Mean Annual Increment	12.00 odMg/ha/yr		
Biomass value	\$40.00 \$/odMg		
Distance to mill	40 km		
Land costs	\$50.00 /ha/yr		
Total Herbicide	\$65.00 /ha		
Ploughing	\$20.00 /ha		
Disking	\$20.00 /ha		
cultivate	\$10.00 /ha		
Site Preparation	\$115.00 /ha		
Planting	\$400.00 /ha		
Cut Back	\$250.00 /ha		
Fertilize	\$100.00 /ha/application		
Weed Control	\$30.00 /ha/application		
Harvest Biomass	\$215.00 /ha/harv.	3.58 /odMg	
chipping	\$300.00 /ha	5.00 /odMg	
Transport to mill	\$360.00 /ha	0.15 /odMg/km	

TABLE 2. CASH FLOW BASED ON LOW INPUT COSTS

		Rotation: 5 years			MAI: 12					
		Density: 10000			NPV: \$697					
		REVENUE			COSTS					
Year or a	+SELL	+LAND	+SITE	+PLAN	+WEED	+FERT	+CUT	+HARV	+CHIP	+TRAN
0	0	50	115	400	0	0	0	0	0	0
1	0	50	0	0	30	0	250	0	0	0
2	0	50	0	0	30	0	0	0	0	0
3	0	50	0	0	0	100	0	0	0	0
4	0	50	0	0	0	100	0	0	0	0
5	0	50	0	0	0	0	0	0	0	0
6	0	50	0	0	30	0	0	215	0	0
7	2400	50	0	0	30	0	0	0	300	360
8	0	50	0	0	0	100	0	0	0	0
9	0	50	0	0	0	100	0	0	0	0
10	0	50	0	0	0	0	0	0	0	0
11	0	50	0	0	30	0	0	215	0	0
12	2400	50	0	0	30	0	0	0	300	360
13	0	50	0	0	0	100	0	0	0	0
14	0	50	0	0	0	100	0	0	0	0
15	0	50	0	0	0	0	0	0	0	0
16	0	50	0	0	0	0	0	215	0	0
17	2400	0	0	0	0	0	0	0	300	360
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
NPV	4,089.16	592	115	400	134	404	238	385	511	613
% of		17%	3%	12%	4%	12%	7%	11%	15%	18%

TABLE 3 CASH FLOW BASED ON LOW INPUT COSTS

Rotation:	5 years	MAI:	12
Density:	10000	NPV:	\$697

		Product Value			Break-even
		\$20	\$40	\$60	Value
MAI -->	+NPV 5	-2557.10	-1644.82	-732.5300	\$76.06
	10	-2146.57	-322.00	1502.5728	\$43.53
	20	-1325.52	2323.63	5972.7786	\$27.26
Break-even		36.10	11.20	6.60	

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	1231.59	3968.45	6705.31
mean	11.67	-2009.73	118.94	2247.61
slope		82.11	264.56	447.02
y-int		-2967.63	-2967.63	-2967.63

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1824.57	-1644.82	45.61	-3469.39
	10	3649.15	-322.00	91.23	-3971.15
	20	7298.30	2323.63	182.46	-4974.66

TABLE 4. CASH FLOW BASED ON LOW INPUT COSTS

=====					
Rotation:		5 years		MAI:	
Density:		10000		NPV:	
				12	
				\$697	
Year	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
=====					
0	ERR	0.00	565.00	(565.00)	(515.00)
1	-1.58	0.00	879.29	(879.29)	(781.67)
2	ERR	0.00	951.85	(951.85)	(808.88)
3	-1.81	0.00	1,081.42	(1,081.42)	(895.26)
4	ERR	0.00	1,204.83	(1,204.83)	(977.53)
5	-1.56	0.00	1,244.01	(1,244.01)	(977.53)
6	ERR	0.00	1,464.14	(1,464.14)	(1,160.35)
7	0.01	1,705.64	1,990.04	(284.41)	54.91
8	-0.01	1,705.64	2,091.57	(385.93)	(12.77)
9	-0.04	1,705.64	2,188.26	(482.63)	(77.23)
10	-0.05	1,705.64	2,218.96	(513.32)	(77.23)
11	ERR	1,705.64	2,391.44	(685.80)	(220.48)
12	0.07	3,042.04	2,803.50	238.55	731.71
13	0.07	3,042.04	2,883.04	159.00	678.68
14	0.06	3,042.04	2,958.80	83.24	628.17
15	0.06	3,042.04	2,982.86	59.19	628.17
16	0.04	3,042.04	3,104.25	(62.21)	529.68
17	0.10	4,089.16	3,392.21	696.95	1,288.83
18	0.10	4,089.16	3,392.21	696.95	1,288.83
19	0.10	4,089.16	3,392.21	696.95	1,288.83
20	0.10	4,089.16	3,392.21	696.95	1,288.83
21	0.10	4,089.16	3,392.21	696.95	1,288.83
22	0.10	4,089.16	3,392.21	696.95	1,288.83
23	0.10	4,089.16	3,392.21	696.95	1,288.83
24	0.10	4,089.16	3,392.21	696.95	1,288.83
25	0.10	4,089.16	3,392.21	696.95	1,288.83
26	0.10	4,089.16	3,392.21	696.95	1,288.83
27	0.10	4,089.16	3,392.21	696.95	1,288.83
28	0.10	4,089.16	3,392.21	696.95	1,288.83
29	0.10	4,089.16	3,392.21	696.95	1,288.83

TABLE 1

CASH FLOW BASED ON LOW INPUT COSTS
20000 SPH

ACTIVITY	VALUE	
Life of Plantation	18 years	
Rotation length	4 years	
Number of Harvests	4	
Mean Annual Increment	12 Mg/ha/yr	
Total Yield/harvest	48.00 Mg/ha	
Total Yield for plantation	192.00 Mg/ha	
Value of Harvested Biomass	\$1,920.00 /ha	
Discounted Total Yield	109.47 Mg/ha	
Present Value of Costs	\$4,171.85	\$38.11 /odMg
Present Value of Revenues	\$4,378.98	\$40.00 /odMg
Net Present Value	\$207.13	\$1.89 /odMg
Annual Equivalent Cost	\$356.89	
Annual Equiv. Net Value	\$17.72	
Internal Rate of Return	6.20%	
Benefit/Cost ratio	1.05	
Interest Rate	0.05	
Density	20,000 stem per ha	
Mean Annual Increment	12.00 odMg/ha/yr	
Biomass value	\$40.00 \$/odMg	
Distance to mill	40 km	
Land costs	\$50.00 /ha/yr	
Total Herbicide	\$65.00 /ha	
Ploughing	\$20.00 /ha	
Disking	\$20.00 /ha	
cultivate	\$10.00 /ha	
Site Preparation	\$115.00 /ha	Cost for
Planting	\$800.00 /ha	cuttings planting
Cut Back	\$250.00 /ha	25.00 15.00
Fertilize	\$100.00 /ha/application	
Weed Control	\$30.00 /ha/application	
Harvest Biomass	\$215.00 /ha/harv.	4.48 /odMg
chipping	\$240.00 /ha	5.00 /odMg
Transport to mill	\$288.00 /ha	0.15 /odMg/km

TABLE 2. CASH FLOW BASED ON LOW INPUT COSTS

=====										
Rotation: 4 years		MAI: 12								
Density: 20000		NPV: \$207		Page 2						
REVENUE		COSTS								
Year or a	+SELL	+LAND	+SITE	+PLAN	+WEED	+FERT	+CUT	+HARV	+CHIP	+TRAN
=====										
0	0	50	115	800	0	0	0	0	0	0
1	0	50	0	0	30	0	250	0	0	0
2	0	50	0	0	30	0	0	0	0	0
3	0	50	0	0	0	100	0	0	0	0
4	0	50	0	0	0	100	0	0	0	0
5	0	50	0	0	30	0	0	215	0	0
6	1920	50	0	0	30	0	0	0	240	288
7	0	50	0	0	0	100	0	0	0	0
8	0	50	0	0	0	100	0	0	0	0
9	0	50	0	0	30	0	0	215	0	0
10	1920	50	0	0	30	0	0	0	240	288
11	0	50	0	0	0	100	0	0	0	0
12	0	50	0	0	0	100	0	0	0	0
13	0	50	0	0	30	0	0	215	0	0
14	1920	50	0	0	30	0	0	0	240	288
15	0	50	0	0	0	100	0	0	0	0
16	0	50	0	0	0	100	0	0	0	0
17	0	50	0	0	0	0	0	215	0	0
18	1920	0	0	0	0	0	0	0	240	288
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
=====										
NPV	4,378.98	614	115	800	170	515	238	515	547	657
% of		15%	3%	19%	4%	12%	6%	12%	13%	16%

TABLE 3 CASH FLOW BASED ON LOW INPUT COSTS

Rotation:	4 years	MAI:	12
Density:	20000	NPV:	\$207

		Product Value			Break-even
		\$20	\$40	\$60	Value
MAI -->	+NPV 5	-2557.10	-1644.82	-732.5300	\$76.06
	10	-2146.57	-322.00	1502.5728	\$43.53
	20	-1325.52	2323.63	5972.7786	\$27.26
Break-even		36.10	11.20	6.60	

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	1231.59	3968.45	6705.31
mean	11.67	-2009.73	118.94	2247.61
slope		82.11	264.56	447.02
y-int		-2967.63	-2967.63	-2967.63

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1824.57	-1644.82	45.61	-3469.39
	10	3649.15	-322.00	91.23	-3971.15
	20	7298.30	2323.63	182.46	-4974.66

TABLE 4. CASH FLOW BASED ON LOW INPUT COSTS

=====					
Rotation:		4 years		MAI: 12	
Density:		20000		NPV: \$207	
Year	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
=====					
0	ERR	0.00	965.00	(965.00)	(915.00)
1	-1.34	0.00	1,279.29	(1,279.29)	(1,181.67)
2	ERR	0.00	1,351.85	(1,351.85)	(1,208.88)
3	-1.62	0.00	1,481.42	(1,481.42)	(1,295.26)
4	ERR	0.00	1,604.83	(1,604.83)	(1,377.53)
5	-1.83	0.00	1,835.97	(1,835.97)	(1,569.50)
6	-0.09	1,432.73	2,289.67	(856.93)	(553.15)
7	-0.12	1,432.73	2,396.27	(963.54)	(624.22)
8	-0.17	1,432.73	2,497.80	(1,065.06)	(691.90)
9	ERR	1,432.73	2,687.96	(1,255.22)	(849.83)
10	0.00	2,611.45	3,061.22	(449.77)	(13.68)
11	-0.01	2,611.45	3,148.92	(537.47)	(72.15)
12	-0.02	2,611.45	3,232.44	(621.00)	(127.83)
13	-0.07	2,611.45	3,388.89	(777.44)	(257.76)
14	0.04	3,581.18	3,695.97	(114.79)	430.14
15	0.04	3,581.18	3,768.12	(186.94)	382.04
16	0.03	3,581.18	3,836.84	(255.66)	336.23
17	0.02	3,581.18	3,952.46	(371.28)	242.42
18	0.06	4,378.98	4,171.85	207.13	820.83
19	0.06	4,378.98	4,171.85	207.13	820.83
20	0.06	4,378.98	4,171.85	207.13	820.83
21	0.06	4,378.98	4,171.85	207.13	820.83
22	0.06	4,378.98	4,171.85	207.13	820.83
23	0.06	4,378.98	4,171.85	207.13	820.83
24	0.06	4,378.98	4,171.85	207.13	820.83
25	0.06	4,378.98	4,171.85	207.13	820.83
26	0.06	4,378.98	4,171.85	207.13	820.83
27	0.06	4,378.98	4,171.85	207.13	820.83
28	0.06	4,378.98	4,171.85	207.13	820.83
29	0.06	4,378.98	4,171.85	207.13	820.83

TABLE 1. Cash flow for current input costs
ACTIVITY VALUE 10000 SPH

Life of Plantation	17 years		
Rotation length	5 years		
Number of Harvests	3		
Mean Annual Increment	12 Mg/ha/yr		
Total Yield/harvest	60.00 Mg/ha		
Total Yield for plantation	180.00 Mg/ha		
Value of Harvested Biomass	\$2,400.00 /ha		
Discounted Total Yield	102.23 Mg/ha		
Present Value of Costs	\$6,211.54	\$60.76 /odMg	
Present Value of Revenues	\$4,089.16	\$40.00 /odMg	
Net Present Value	(\$2,122.39)	(\$20.76) /odMg	
Annual Equivalent Cost	\$550.96		
Annual Equiv. Net Value	(\$188.25)		
Internal Rate of Return	-11.11%		
Benefit/Cost ratio	0.66		
Interest Rate	0.05		
Density	10,000 stem per ha		
Mean Annual Increment	12.00 odMg/ha/yr		
Biomass value	\$40.00 \$/odMg		
Distance to mill	40 km		
Land costs	\$75.00 /ha/yr		
Total Herbicide	\$85.00 /ha		
Ploughing	\$44.00 /ha		
Disking	\$25.00 /ha		
cultivate	\$21.00 /ha		
Site Preparation	\$175.00 /ha	Cost for	
Planting	\$780.00 /ha	cuttings planting	
Cut Back	\$375.00 /ha	50.00	28.00
Fertilize	\$150.00 /ha/application		
Weed Control	\$30.00 /ha/application		
Harvest Biomass	\$800.00 /ha/harv.	13.33 /odMg	
chipping	\$600.00 /ha	10.00 /odMg	
Transport to mill	\$480.00 /ha	0.20 /odMg/km	

TABLE 2. Cash flow for current input costs

=====										
Rotation: 5 years		MAI: 12								
Density: 10000		NPV: *****		Page 2						
REVENUE		COSTS								
Year or a	+SELL	+LAND	+SITE	+PLAN	+WEED	+FERT	+CUT	+HARV	+CHIP	+TRAN
=====										
0	0	75	175	780	0	0	0	0	0	0
1	0	75	0	0	30	0	375	0	0	0
2	0	75	0	0	30	0	0	0	0	0
3	0	75	0	0	0	150	0	0	0	0
4	0	75	0	0	0	150	0	0	0	0
5	0	75	0	0	0	0	0	0	0	0
6	0	75	0	0	30	0	0	800	0	0
7	2400	75	0	0	30	0	0	0	600	480
8	0	75	0	0	0	150	0	0	0	0
9	0	75	0	0	0	150	0	0	0	0
10	0	75	0	0	0	0	0	0	0	0
11	0	75	0	0	30	0	0	800	0	0
12	2400	75	0	0	30	0	0	0	600	480
13	0	75	0	0	0	150	0	0	0	0
14	0	75	0	0	0	150	0	0	0	0
15	0	75	0	0	0	0	0	0	0	0
16	0	75	0	0	0	0	0	800	0	0
17	2400	0	0	0	0	0	0	0	600	480
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
=====										
NPV	4,089.16	888	175	780	134	607	357	1431	1022	818
% of		14%	3%	13%	2%	10%	6%	23%	16%	13%

TABLE 3 Cash flow for current input costs

Rotation:	5 years	MAI:	12
Density:	10000	NPV:	(\$2,122)

		Product Value			Break-even
		\$20	\$40	\$60	Value
MAI -->	5	-4286.23	-3434.32	-2582.415	\$120.63
	10	-4201.04	-2497.22	-793.4094	\$69.31
	20	-4030.66	-623.03	2784.6029	\$43.66
Break-even		256.60	23.30	12.20	

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	255.57	2811.30	5367.02
mean	11.67	-4172.64	-2184.86	-197.07
slope		17.04	187.42	357.80
y-int		-4371.42	-4371.42	-4371.42

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1703.82	-3434.32	42.60	-5138.14
	10	3407.63	-2497.22	85.19	-5904.86
	20	6815.26	-623.03	170.38	-7438.29

TABLE 4. Cash flow for current input costs

=====					
Rotation:		5 years		MAI: 12	
Density:		10000		NPV: (\$2,122)	
Year	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
=====					
0	ERR	0.00	1,030.00	(1,030.00)	(955.00)
1	-1.47	0.00	1,487.14	(1,487.14)	(1,340.71)
2	ERR	0.00	1,582.38	(1,582.38)	(1,367.93)
3	-1.73	0.00	1,776.74	(1,776.74)	(1,497.50)
4	ERR	0.00	1,961.85	(1,961.85)	(1,620.91)
5	-1.52	0.00	2,020.62	(2,020.62)	(1,620.91)
6	ERR	0.00	2,695.94	(2,695.94)	(2,240.26)
7	-0.23	1,705.64	3,538.10	(1,832.46)	(1,323.49)
8	-0.33	1,705.64	3,690.39	(1,984.75)	(1,425.01)
9	ERR	1,705.64	3,835.43	(2,129.79)	(1,521.70)
10	ERR	1,705.64	3,881.47	(2,175.83)	(1,521.70)
11	ERR	1,705.64	4,410.60	(2,704.97)	(2,006.99)
12	-0.16	3,042.04	5,070.46	(2,028.41)	(1,288.67)
13	-0.23	3,042.04	5,189.78	(2,147.73)	(1,368.22)
14	ERR	3,042.04	5,303.42	(2,261.37)	(1,443.98)
15	ERR	3,042.04	5,339.49	(2,297.45)	(1,443.98)
16	ERR	3,042.04	5,740.34	(2,698.30)	(1,810.46)
17	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
18	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
19	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
20	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
21	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
22	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
23	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
24	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
25	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
26	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
27	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
28	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)
29	-0.11	4,089.16	6,211.54	(2,122.39)	(1,234.55)

TABLE 1. FUTURE VALUE 10000 SPH

ACTIVITY	VALUE	10000 SPH
Life of Plantation	17 years	
Rotation length	5 years	
Number of Harvests	3	
Mean Annual Increment	20 Mg/ha/yr	
Total Yield/harvest	100.00 Mg/ha	
Total Yield for plantation	300.00 Mg/ha	
Value of Harvested Biomass	\$4,500.00 /ha	
Discounted Total Yield	170.38 Mg/ha	
Present Value of Costs	\$5,889.75	\$34.57 /odMg
Present Value of Revenues	\$7,667.17	\$45.00 /odMg
Net Present Value	\$1,777.42	\$10.43 /odMg
Annual Equivalent Cost	\$522.42	
Annual Equiv. Net Value	\$157.66	
Internal Rate of Return	14.01%	
Benefit/Cost ratio	1.30	
Interest Rate	0.05	
Density	10,000 stem per ha	
Mean Annual Increment	20.00 odMg/ha/yr	
Biomass value	\$45.00 \$/odMg	
Distance to mill	40 km	
Land costs	\$75.00 /ha/yr	
Total Herbicide	\$45.00 /ha	
Ploughing	\$27.00 /ha	
Disking	\$15.00 /ha	
cultivate	\$13.00 /ha	
Site Preparation	\$100.00 /ha	Cost for
Planting	\$710.00 /ha	cuttings planting
Cut Back	\$0.00 /ha	50.00 21.00
Fertilize	\$75.00 /ha/application	
Weed Control	\$20.00 /ha/application	
Harvest Biomass	\$600.00 /ha/harv.	6.00 /odMg
chipping	\$800.00 /ha	8.00 /odMg
Transport to mill	\$800.00 /ha	0.20 /odMg/km

TABLE 2. FUTURE1

Page 2

	Rotation:	5 years			MAI:	20				
	Density:	10000			NPV:	*****		Page 2		
	REVENUE	COSTS								
Year or a	+SELL	+LAND	+SITE	+PLAN	+WEED	+FERT	+CUT	+HARV	+CHIP	+TRAN
0	0	75	100	710	0	0	0	0	0	0
1	0	75	0	0	20	0	0	0	0	0
2	0	75	0	0	20	0	0	0	0	0
3	0	75	0	0	0	75	0	0	0	0
4	0	75	0	0	0	75	0	0	0	0
5	0	75	0	0	0	0	0	0	0	0
6	0	75	0	0	20	0	0	600	0	0
7	4500	75	0	0	20	0	0	0	800	800
8	0	75	0	0	0	75	0	0	0	0
9	0	75	0	0	0	75	0	0	0	0
10	0	75	0	0	0	0	0	0	0	0
11	0	75	0	0	20	0	0	600	0	0
12	4500	75	0	0	20	0	0	0	800	800
13	0	75	0	0	0	75	0	0	0	0
14	0	75	0	0	0	75	0	0	0	0
15	0	75	0	0	0	0	0	0	0	0
16	0	75	0	0	0	0	0	600	0	0
17	4500	0	0	0	0	0	0	0	800	800
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
NPV	7,667.17	888	100	710	89	303	0	1073	1363	1363
% of		15%	2%	12%	2%	5%	0%	18%	23%	23%

TABLE 3 FUTURE1

Rotation:	5 years	MAI:	20
Density:	10000	NPV:	\$1,777

		Product Value			Break-even
		\$20	\$40	\$60	Value
MAI -->	+NPV 5	-2993.26	-2141.36	-1289.449	\$90.27
	10	-2822.88	-1119.07	584.74771	\$53.14
	20	-2482.12	925.51	4333.1416	\$34.57
Break-even		92.80	15.50	8.40	

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	511.14	3066.87	5622.59
mean	11.67	-2766.09	-778.30	1209.48
slope		34.08	204.46	374.84
y-int		-3163.65	-3163.65	-3163.65

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1703.82	-2141.36	42.60	-3845.17
	10	3407.63	-1119.07	85.19	-4526.70
	20	6815.26	925.51	170.38	-5889.75

TABLE 4. FUTURE1

=====					
Rotation:		5 years		MAI:	20
Density:		10000		NPV:	\$1,777
Year	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
=====					
0	ERR	0.00	885.00	(885.00)	(810.00)
1	-1.11	0.00	975.48	(975.48)	(829.05)
2	ERR	0.00	1,061.64	(1,061.64)	(847.19)
3	-1.52	0.00	1,191.22	(1,191.22)	(911.98)
4	ERR	0.00	1,314.63	(1,314.63)	(973.68)
5	-1.51	0.00	1,373.39	(1,373.39)	(973.68)
6	ERR	0.00	1,892.01	(1,892.01)	(1,436.33)
7	0.06	3,198.07	3,096.61	101.45	610.43
8	0.05	3,198.07	3,198.14	(0.07)	559.67
9	0.04	3,198.07	3,294.83	(96.77)	511.32
10	0.03	3,198.07	3,340.87	(142.81)	511.32
11	ERR	3,198.07	3,747.23	(549.16)	148.82
12	0.12	5,703.83	4,691.07	1,012.77	1,752.51
13	0.12	5,703.83	4,770.61	933.22	1,712.74
14	0.11	5,703.83	4,846.37	857.46	1,674.86
15	0.11	5,703.83	4,882.45	821.38	1,674.86
16	0.10	5,703.83	5,191.68	512.16	1,399.99
17	0.14	7,667.17	5,889.75	1,777.42	2,665.25
18	0.14	7,667.17	5,889.75	1,777.42	2,665.25
19	0.14	7,667.17	5,889.75	1,777.42	2,665.25
20	0.14	7,667.17	5,889.75	1,777.42	2,665.25
21	0.14	7,667.17	5,889.75	1,777.42	2,665.25
22	0.14	7,667.17	5,889.75	1,777.42	2,665.25
23	0.14	7,667.17	5,889.75	1,777.42	2,665.25
24	0.14	7,667.17	5,889.75	1,777.42	2,665.25
25	0.14	7,667.17	5,889.75	1,777.42	2,665.25
26	0.14	7,667.17	5,889.75	1,777.42	2,665.25
27	0.14	7,667.17	5,889.75	1,777.42	2,665.25
28	0.14	7,667.17	5,889.75	1,777.42	2,665.25
29	0.14	7,667.17	5,889.75	1,777.42	2,665.25

TABLE 1.

SUBSIDIZED
VALUE

10000 SPH

ACTIVITY	VALUE	10000 SPH
Life of Plantation	17 years	
Rotation length	5 years	
Number of Harvests	3	
Mean Annual Increment	20 Mg/ha/yr	
Total Yield/harvest	100.00 Mg/ha	
Total Yield for plantation	300.00 Mg/ha	
Value of Harvested Biomass	\$4,500.00 /ha	
Discounted Total Yield	200.69 Mg/ha	
Present Value of Costs	\$4,501.92	\$22.43 /odMg
Present Value of Revenues	\$9,030.95	\$45.00 /odMg
Net Present Value	\$4,529.04	\$22.57 /odMg
Annual Equivalent Cost	\$399.32	
Annual Equiv. Net Value	\$401.72	
Internal Rate of Return	ERR	
Benefit/Cost ratio	2.01	
Interest Rate	0.05	
Density	10,000 stem per ha	
Mean Annual Increment	20.00 odMg/ha/yr	
Biomass value	\$45.00 \$/odMg	
Distance to mill	40 km	
Land costs	\$0.00 /ha/yr	
Total Herbicide	\$45.00 /ha	
Ploughing	\$27.00 /ha	
Disking	\$15.00 /ha	
cultivate	\$13.00 /ha	
Site Preparation	\$100.00 /ha	Cost for
Planting	\$210.00 /ha	cuttings planting
Cut Back	\$0.00 /ha	0.00 21.00
Fertilize	\$75.00 /ha/application	
Weed Control	\$20.00 /ha/application	
Harvest Biomass	\$600.00 /ha/harv.	6.00 /odMg
chipping	\$800.00 /ha	8.00 /odMg
Transport to mill	\$800.00 /ha	0.20 /odMg/km
Subsidy 1	\$300.00 /ha	
Subsidy 2	\$0.00 /ha	
Subsidy 3	\$0.00 /ha	

TABLE 2. SUBSIDIZED

=====				
	Rotation:	5 years		
	Density:	10000	MAI:	20
		REVENUE	NPV:	\$4,529
Year or a	+SELL	+SUB1	+SUB2	+SUB3
=====				
0	0	300	0	0
1	0	300	0	0
2	0	300	0	0
3	0	300	0	0
4	0	300	0	0
5	0	0	0	0
6	0	0	0	0
7	4500	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	4500	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	4500	0	0	0
18	0	0	0	0
19	0	0	0	0
20	0	0	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0
25	0	0	0	0
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
=====				
NPV	7,667.17	1,363.79	0.00	0.00
% of	85%	15%	0%	0%

TABLE 3 SUBSIDIZED

Rotation:	5 years	MAI:	20
Density:	10000	NPV:	\$4,529

		Product Value			Break-even
		\$20	\$40	\$60	Value
MAI -->	5	-241.65	610.26	1462.1686	\$25.67
	10	-71.27	1632.55	3336.3655	\$20.84
	20	269.50	3677.13	7084.7595	\$18.42
Break-even		12.10	2.00	1.10	

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	511.14	3066.87	5622.59
mean	11.67	-14.47	1973.31	3961.10
slope		34.08	204.46	374.84
y-int		-412.03	-412.03	-412.03

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1703.82	610.26	42.60	-1093.55
	10	3407.63	1632.55	85.19	-1775.08
	20	6815.26	3677.13	170.38	-3138.13

TABLE 4. SUBSIDIZED

=====					
Rotation:		5 years		MAI: 20	
Density:		10000		NPV: \$4,529	
Year	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
=====					
0	ERR	300.00	310.00	(10.00)	(10.00)
1	27.00	585.71	329.05	256.67	256.67
2	-1.97	857.82	347.19	510.63	510.63
3	ERR	1,116.97	411.98	705.00	705.00
4	-1.98	1,363.79	473.68	890.11	890.11
5	-1.00	1,363.79	473.68	890.11	890.11
6	-0.13	1,363.79	936.33	427.45	427.45
7	ERR	4,561.85	2,087.64	2,474.22	2,474.22
8	-0.97	4,561.85	2,138.40	2,423.45	2,423.45
9	-0.82	4,561.85	2,186.74	2,375.11	2,375.11
10	-0.82	4,561.85	2,186.74	2,375.11	2,375.11
11	-0.29	4,561.85	2,549.25	2,012.61	2,012.61
12	-2.00	7,067.62	3,451.32	3,616.30	3,616.30
13	-0.97	7,067.62	3,491.10	3,576.52	3,576.52
14	-0.82	7,067.62	3,528.98	3,538.64	3,538.64
15	-0.82	7,067.62	3,528.98	3,538.64	3,538.64
16	-0.31	7,067.62	3,803.84	3,263.78	3,263.78
17	ERR	9,030.95	4,501.92	4,529.04	4,529.04
18	-1.00	9,030.95	4,501.92	4,529.04	4,529.04
19	ERR	9,030.95	4,501.92	4,529.04	4,529.04
20	ERR	9,030.95	4,501.92	4,529.04	4,529.04
21	ERR	9,030.95	4,501.92	4,529.04	4,529.04
22	ERR	9,030.95	4,501.92	4,529.04	4,529.04
23	ERR	9,030.95	4,501.92	4,529.04	4,529.04
24	ERR	9,030.95	4,501.92	4,529.04	4,529.04
25	ERR	9,030.95	4,501.92	4,529.04	4,529.04
26	ERR	9,030.95	4,501.92	4,529.04	4,529.04
27	ERR	9,030.95	4,501.92	4,529.04	4,529.04
28	ERR	9,030.95	4,501.92	4,529.04	4,529.04
29	ERR	9,030.95	4,501.92	4,529.04	4,529.04

TABLE 1. Current input costs with farm labour
 ACTIVITY VALUE 10000 SPH

Life of Plantation	17 years		
Rotation length	5 years		
Number of Harvests	3		
Mean Annual Increment	12 Mg/ha/yr		
Total Yield/harvest	60.00 Mg/ha		
Total Yield for plantation	180.00 Mg/ha		
Value of Harvested Biomass	\$2,400.00 /ha		
Discounted Total Yield	102.23 Mg/ha		
Present Value of Costs	\$5,431.57	\$53.13 /odMg	
Present Value of Revenues	\$4,089.16	\$40.00 /odMg	
Net Present Value	(\$1,342.41)	(\$13.13)/odMg	
Annual Equivalent Cost	\$481.78		
Annual Equiv. Net Value	(\$119.07)		
Internal Rate of Return	-7.21%		
Benefit/Cost ratio	0.75		
Interest Rate	0.05		
Density	10,000 stem per ha		
Mean Annual Increment	12.00 odMg/ha/yr		
Biomass value	\$40.00 \$/odMg		
Distance to mill	40 km		
Land costs	\$75.00 /ha/yr		
Total Herbicide	\$45.00 /ha		
Ploughing	\$27.00 /ha		
Disking	\$15.00 /ha		
cultivate	\$13.00 /ha		
Site Preparation	\$100.00 /ha	Cost for	
Planting	\$780.00 /ha	cuttings	planting
Cut Back	\$0.00 /ha	50.00	28.00
Fertilize	\$75.00 /ha/application		
Weed Control	\$20.00 /ha/application		
Harvest Biomass	\$800.00 /ha/harv.	13.33 /odMg	
chipping	\$600.00 /ha	10.00 /odMg	
Transport to mill	\$480.00 /ha	0.20 /odMg/km	

TABLE 2. Current input costs with farm labour

=====										
Rotation: 5 years		MAI: 12								
Density: 10000		NPV: *****		Page 2						
REVENUE		COSTS								
Year or a	+SELL	+LAND	+SITE	+PLAN	+WEED	+FERT	+CUT	+HARV	+CHIP	+TRAN
=====										
0	0	75	100	780	0	0	0	0	0	0
1	0	75	0	0	20	0	0	0	0	0
2	0	75	0	0	20	0	0	0	0	0
3	0	75	0	0	0	75	0	0	0	0
4	0	75	0	0	0	75	0	0	0	0
5	0	75	0	0	0	0	0	0	0	0
6	0	75	0	0	20	0	0	800	0	0
7	2400	75	0	0	20	0	0	0	600	480
8	0	75	0	0	0	75	0	0	0	0
9	0	75	0	0	0	75	0	0	0	0
10	0	75	0	0	0	0	0	0	0	0
11	0	75	0	0	20	0	0	800	0	0
12	2400	75	0	0	20	0	0	0	600	480
13	0	75	0	0	0	75	0	0	0	0
14	0	75	0	0	0	75	0	0	0	0
15	0	75	0	0	0	0	0	0	0	0
16	0	75	0	0	0	0	0	800	0	0
17	2400	0	0	0	0	0	0	0	600	480
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
=====										
NPV	4,089.16	888	100	780	89	303	0	1431	1022	818
% of		16%	2%	14%	2%	6%	0%	26%	19%	15%

TABLE 3 Current input costs with farm labour

Rotation:	5 years	MAI:	12
Density:	10000	NPV:	(\$1,342)

		Product Value			Break-even
		\$20	\$40	\$60	Value
MAI -->	5	-3506.26	-2654.35	-1802.441	\$102.32
	10	-3421.07	-1717.25	-13.43506	\$60.16
	20	-3250.68	156.95	3564.5773	\$39.08
Break-even		210.80	19.20	10.00	

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	255.57	2811.30	5367.02
mean	11.67	-3392.67	-1404.88	582.90
slope		17.04	187.42	357.80
y-int		-3591.45	-3591.45	-3591.45

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1703.82	-2654.35	42.60	-4358.16
	10	3407.63	-1717.25	85.19	-5124.88
	20	6815.26	156.95	170.38	-6658.32

TABLE 4. Current input costs with farm labour

Rotation:		5 years		MAI: 12	
Density:		10000		NPV: (\$1,342)	
Year	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
0	ERR	0.00	955.00	(955.00)	(880.00)
1	-1.10	0.00	1,045.48	(1,045.48)	(899.05)
2	ERR	0.00	1,131.64	(1,131.64)	(917.19)
3	-1.51	0.00	1,261.22	(1,261.22)	(981.98)
4	ERR	0.00	1,384.63	(1,384.63)	(1,043.68)
5	-1.51	0.00	1,443.39	(1,443.39)	(1,043.68)
6	ERR	0.00	2,111.25	(2,111.25)	(1,655.58)
7	-0.18	1,705.64	2,946.30	(1,240.67)	(731.69)
8	-0.24	1,705.64	3,047.83	(1,342.19)	(782.45)
9	ERR	1,705.64	3,144.52	(1,438.88)	(830.80)
10	ERR	1,705.64	3,190.56	(1,484.93)	(830.80)
11	ERR	1,705.64	3,713.85	(2,008.22)	(1,310.24)
12	-0.11	3,042.04	4,368.14	(1,326.09)	(586.35)
13	-0.15	3,042.04	4,447.68	(1,405.64)	(626.12)
14	-0.26	3,042.04	4,523.44	(1,481.40)	(664.00)
15	ERR	3,042.04	4,559.52	(1,517.48)	(664.00)
16	ERR	3,042.04	4,960.37	(1,918.32)	(1,030.49)
17	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
18	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
19	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
20	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
21	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
22	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
23	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
24	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
25	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
26	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
27	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
28	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)
29	-0.07	4,089.16	5,431.57	(1,342.41)	(454.58)

TABLE 1. Future input costs, by contractor
 ACTIVITY VALUE 10000 SPH

Life of Plantation	17 years		
Rotation length	5 years		
Number of Harvests	3		
Mean Annual Increment	20 Mg/ha/yr		
Total Yield/harvest	100.00 Mg/ha		
Total Yield for plantation	300.00 Mg/ha		
Value of Harvested Biomass	\$4,500.00 /ha		
Discounted Total Yield	170.38 Mg/ha		
Present Value of Costs	\$7,438.29	\$43.66 /odMg	
Present Value of Revenues	\$7,667.17	\$45.00 /odMg	
Net Present Value	\$228.88	\$1.34 /odMg	
Annual Equivalent Cost	\$659.77		
Annual Equiv. Net Value	\$20.30		
Internal Rate of Return	6.03%		
Benefit/Cost ratio	1.03		
Interest Rate	0.05		
Density	10,000 stem per ha		
Mean Annual Increment	20.00 odMg/ha/yr		
Biomass value	\$45.00 /odMg		
Distance to mill	40 km		
Land costs	\$75.00 /ha/yr		
Total Herbicide	\$85.00 /ha		
Ploughing	\$44.00 /ha		
Disking	\$25.00 /ha		
cultivate	\$21.00 /ha		
Site Preparation	\$175.00 /ha	Cost for	
Planting	\$780.00 /ha	cuttings planting	
Cut Back	\$375.00 /ha	50.00	28.00
Fertilize	\$150.00 /ha/application		
Weed Control	\$30.00 /ha/application		
Harvest Biomass	\$800.00 /ha/harv.	8.00 /odMg	
chipping	\$1,000.00 /ha	10.00 /odMg	
Transport to mill	\$800.00 /ha	0.20 /odMg/km	

TABLE 2. Future input costs, by contractor

=====										
	Rotation:	5 years			MAI:	20				
	Density:	10000			NPV:	\$229		Page 2		
	REVENUE	COSTS								
Year or a	+SELL	+LAND	+SITE	+PLAN	+WEED	+FERT	+CUT	+HARV	+CHIP	+TRAN
=====										
0	0	75	175	780	0	0	0	0	0	0
1	0	75	0	0	30	0	375	0	0	0
2	0	75	0	0	30	0	0	0	0	0
3	0	75	0	0	0	150	0	0	0	0
4	0	75	0	0	0	150	0	0	0	0
5	0	75	0	0	0	0	0	0	0	0
6	0	75	0	0	30	0	0	800	0	0
7	4500	75	0	0	30	0	0	0	1000	800
8	0	75	0	0	0	150	0	0	0	0
9	0	75	0	0	0	150	0	0	0	0
10	0	75	0	0	0	0	0	0	0	0
11	0	75	0	0	30	0	0	800	0	0
12	4500	75	0	0	30	0	0	0	1000	800
13	0	75	0	0	0	150	0	0	0	0
14	0	75	0	0	0	150	0	0	0	0
15	0	75	0	0	0	0	0	0	0	0
16	0	75	0	0	0	0	0	800	0	0
17	4500	0	0	0	0	0	0	0	1000	800
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
=====										
NPV	7,667.17	888	175	780	134	607	357	1431	1704	1363
% of		12%	2%	10%	2%	8%	5%	19%	23%	18%

TABLE 3 Future input costs, by contractor

Rotation:	5 years	MAI:	20
Density:	10000	NPV:	\$229

		Product Value		Break-even
		\$20	\$40	\$60 Value
MAI -->	+NPV 5	-4286.23	-3434.32	-2582.415 \$120.63
	10	-4201.04	-2497.22	-793.4094 \$69.31
	20	-4030.66	-623.03	2784.6029 \$43.66
Break-even		256.60	23.30	12.20

Regression of NPV on MAI for various product values.

		Product Value		
		\$20	\$40	\$60
change	15.00	255.57	2811.30	5367.02
mean	11.67	-4172.64	-2184.86	-197.07
slope		17.04	187.42	357.80
y-int		-4371.42	-4371.42	-4371.42

Regression of NPV on product value for various product MAIs.

		change	mean	slope	y-int
		40	40		
MAI	5	1703.82	-3434.32	42.60	-5138.14
	10	3407.63	-2497.22	85.19	-5904.86
	20	6815.26	-623.03	170.38	-7438.29

TABLE 4. Future input costs, by contractor

=====					
Rotation:		5 years		MAI: 20	
Density:		10000		NPV: \$229	
Year	IRR	TOTAL REVENUES	TOTAL COSTS	TOTAL	Excluding Land Cost
=====					
0	ERR	0.00	1,030.00	(1,030.00)	(955.00)
1	-1.47	0.00	1,487.14	(1,487.14)	(1,340.71)
2	ERR	0.00	1,582.38	(1,582.38)	(1,367.93)
3	-1.73	0.00	1,776.74	(1,776.74)	(1,497.50)
4	ERR	0.00	1,961.85	(1,961.85)	(1,620.91)
5	-1.52	0.00	2,020.62	(2,020.62)	(1,620.91)
6	ERR	0.00	2,695.94	(2,695.94)	(2,240.26)
7	-0.04	3,198.07	4,049.79	(851.72)	(342.75)
8	-0.06	3,198.07	4,202.08	(1,004.01)	(444.27)
9	-0.09	3,198.07	4,347.12	(1,149.05)	(540.96)
10	-0.10	3,198.07	4,393.16	(1,195.09)	(540.96)
11	ERR	3,198.07	4,922.29	(1,724.23)	(1,026.25)
12	0.03	5,703.83	5,983.07	(279.23)	460.51
13	0.02	5,703.83	6,102.39	(398.56)	380.96
14	0.01	5,703.83	6,216.03	(512.20)	305.20
15	0.01	5,703.83	6,252.11	(548.27)	305.20
16	ERR	5,703.83	6,652.96	(949.12)	(61.29)
17	0.06	7,667.17	7,438.29	228.88	1,116.71
18	0.06	7,667.17	7,438.29	228.88	1,116.71
19	0.06	7,667.17	7,438.29	228.88	1,116.71
20	0.06	7,667.17	7,438.29	228.88	1,116.71
21	0.06	7,667.17	7,438.29	228.88	1,116.71
22	0.06	7,667.17	7,438.29	228.88	1,116.71
23	0.06	7,667.17	7,438.29	228.88	1,116.71
24	0.06	7,667.17	7,438.29	228.88	1,116.71
25	0.06	7,667.17	7,438.29	228.88	1,116.71
26	0.06	7,667.17	7,438.29	228.88	1,116.71
27	0.06	7,667.17	7,438.29	228.88	1,116.71
28	0.06	7,667.17	7,438.29	228.88	1,116.71
29	0.06	7,667.17	7,438.29	228.88	1,116.71

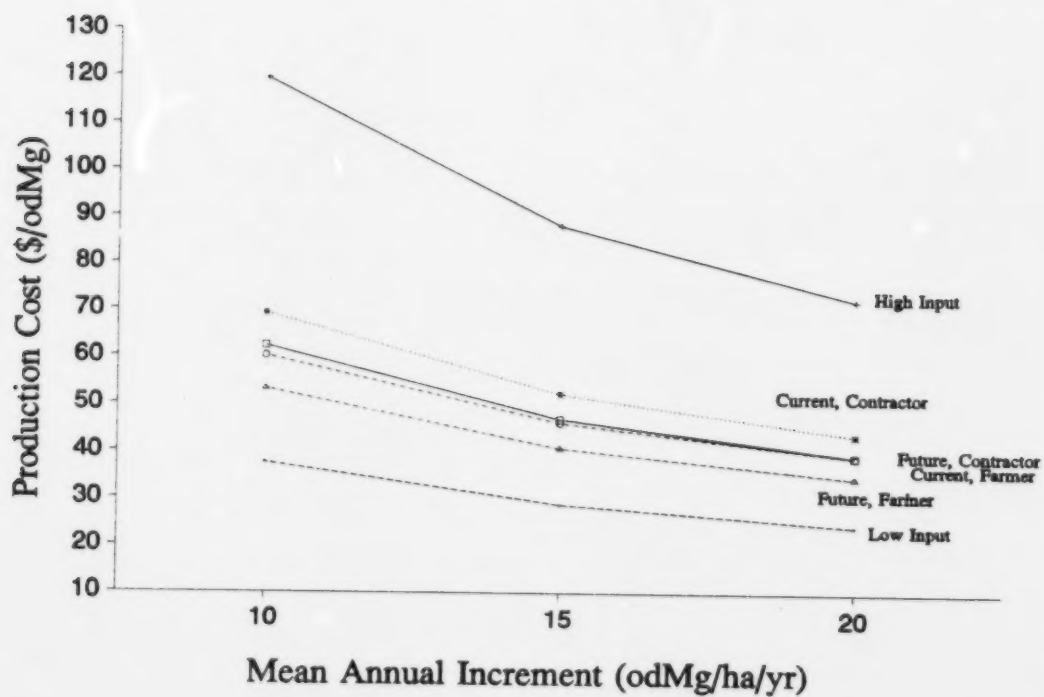


Figure 1 The relationship between mean annual increment and production costs for some scenarios.

APPENDIX G

Comments on the EMR biomass economics spreadsheet:
TREE 1-2-3

Comments On The EMR Biomass Economics Spreadsheet: TREE 1-2-3

A copy of the EMR spreadsheet TREE 1-2-3 was provided by EMR Canada. This computer worksheet was not used in the study for the following reasons:

- work dealing with the cash flow analysis was already begun before the spreadsheet was received; and
- a spreadsheet has been developed to address the specific needs of the project, on a discounted cash flow basis.

The spreadsheet appears to be quite versatile with respect to energy biomass production. This versatility is achieved through substantial user control over inputs, either as single parameters or schedules.

The brief manual provided could be enhanced with a glossary of the terms used and one or two worked examples. In some instances, an indication of how input parameters are applied would improve on the "black box" nature of the spreadsheet. For example, where do depreciation (4.1.2) and loan rate subsidy (4.1.5) apply?

This template will be assessed more extensively as we continue to monitor progress in the development of SRIC systems for the production of energy biomass.